Request by Lamont-Doherty Earth Observatory for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Marine Geophysical Survey by the R/V *Kilo Moana* around the Aleutian Islands, June–July 2005

submitted by

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to

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SUMMARY

Lamont-Doherty Earth Observatory (L-DEO), a part of Columbia University, plans to conduct a low-energy, shallow-penetrating seismic survey and scientific rock dredging program around the Aleutian Islands. The National Science Foundation (NSF), an independent U.S. Government agency, is providing the funding to support the research to be undertaken on the cruise. The geophysical survey will involve the oceanographic research vessel R/V *Kilo Moana*, a U.S. Navy-owned ship operated by the University of Hawaii. The vessel would be using a portable L-DEO seismic system to conduct the seismic survey. As presently scheduled, the survey will occur from 14 June to 20 July 2005. L-DEO requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals incidental to the planned seismic survey around the Aleutian Islands. This request is submitted pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. § 1371 (a) (5). The seismic survey will be conducted in the Exclusive Economic Zone (EEZ) of the U.S.A.

Numerous species of cetaceans and pinnipeds inhabit the area around the Aleutian Islands. Several of the species are listed as "Endangered" under the U.S. Endangered Species Act (ESA), including the humpback, sei, fin, blue, North Pacific right, and sperm whales. Other species of special concern that could occur in the area include the Steller sea lion, for which the western stock is listed as "Endangered" and the eastern stock is listed as "Threatened", and the leatherback turtle, which is listed as "Endangered". The stock of sea otters present in the proposed survey area has recently been proposed for listing as "Threatened". Unlike other marine mammals, which are regulated by NMFS, the sea otter is regulated by the U.S. Fish and Wildlife Service (USFWS). The sea otter was addressed in the Environmental Assessment that accompanies this IHA Application, and a conference will also be conducted with the USFWS regarding project operations and sea otters.

The items required to be addressed pursuant to 50 C.F.R. § 216.104, "Submission of Requests" are set forth below. This includes descriptions of the specific operations to be conducted, the marine mammals occurring in the study area, proposed measures to mitigate against any potential injurious effects on marine mammals, and a plan to monitor any behavioral effects of the operations on those marine mammals.

I. OPERATIONS TO BE CONDUCTED

A detailed description of the specific activity or class of activities that can be expected to result in incidental taking of marine mammals.

Overview of the Activity

Lamont-Doherty Earth Observatory (L-DEO), on behalf of the National Science Foundation, low-energy, shallow-penetrating seismic survey and scientific rock dredging program around the Aleutian Islands (Fig. 1) for about a month, beginning in June 2005.

The purpose of the proposed study is to examine the east-to-west change in the Pacific-North America convergence angle, which implies systematic westward decreases in the rate of subduction and sediment delivery to the Aleutian trench. The changes apparently are also linked to along-arc changes in Aleutian lava geochemistry and rates of magma output. Large volcanoes around 165°W are mostly basaltic and imply high rates of mafic magma production in the east. In contrast, small volcanoes from Adak Island westward imply relatively low magma production rates including the formation of a relatively large proportion of andesite and dacite in addition to basalt.

The Aleutian Island Arc is recognized as an ideal place to carry out the research. It is the only island arc where systematic changes in physical aspects of the subduction system have been well correlated with magma output rates and with the geochemistry of the melts that the system produces. The rates of subduction and sediment delivery to the trench change from east-to-west along the arc. Because of these well-established physical-chemical connections, the Aleutian Arc is uniquely well suited to answer important questions regarding subduction magma genesis. This is particularly true with respect to the interaction between the Earth's surface and the deep interior, which occurs by the process of sediment subduction and which is unusually well characterized in the Aleutians compared to other island arc systems.

Despite its potential importance with regard to our understanding of subduction systems, studies of volcanism in the Aleutians are lacking. In particular, the western Aleutians (west of Adak Island) are now playing a key role in our evolving view of subduction magma genesis, yet remain a poorly studied area. Few volcanic rock samples are available from that area, and it has not been studied substantially at sea.

In addition to an emphasis on magma genesis and its relationship to tectonics, volcanism in the Aleutians and southern Alaska is important because it is well known to present a hazard to air traffic. The seismic and geochemical studies proposed here are not directly hazard-related. However, they are aimed at understanding the deep-level processes that underlie the volcanic eruptions, and are thus relevant to the broad goals of understanding volcano behavior and hazard assessment in the Aleutians and elsewhere.

The seismic survey will involve one vessel. The source vessel, the R/V *Kilo Moana*, will deploy one Generator-injector (GI) airgun as an energy source (discharge volume of 105 in^3), plus a towed hydrophone streamer up to 300 m long, or possibly as short as 50 m. As the GI gun is towed along the survey lines, the receiving system will receive the returning acoustic signals.

The proposed program will consist of ~4112 km of seismic survey, and scientific rock dredging at 10 locations. The seismic survey will take place in water depths <50–3500 m, mostly (>99%) in depths >100 m, and scientific rock dredging will be conducted in water depths 100–1800, mostly in depths >400m.
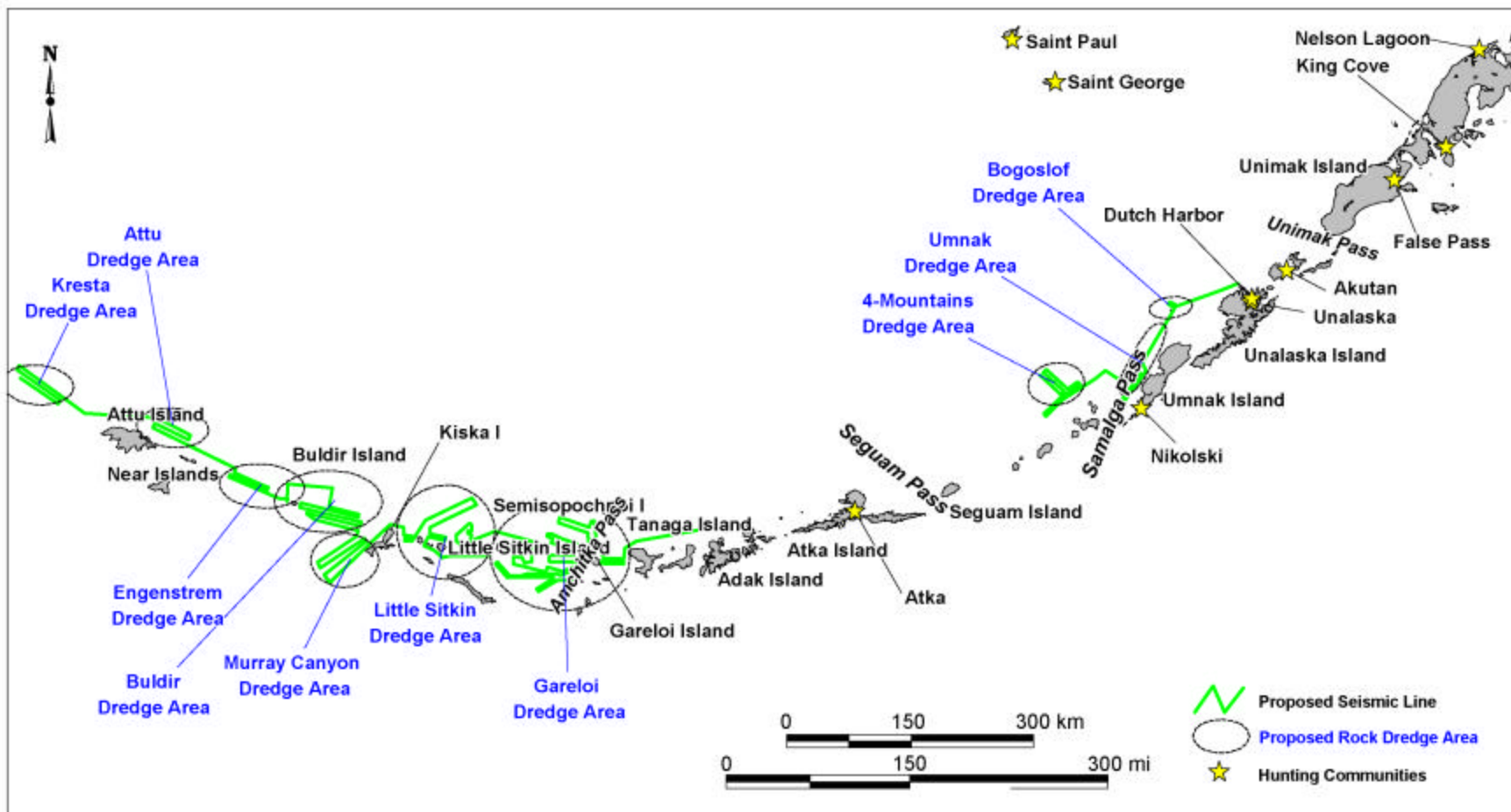
FIGURE 1. Proposed location of L-DEO's June–July 2005 Aleutian Island seismic survey lines and scientific rock dredging areas.

This is an NSF-sponsored collaborative research effort including seismic and scientific rock dredging activities by a group of scientists from several research institutions and universities. The chief scientists are Dr. Gene Yogodzinski of the University of South Carolina, Dr. Peter Kelemen of L-DEO, Dr. H. Gary Greene of Moss Landing Marine Laboratories, and Dr. Brad Singer of the University of Wisconsin. Dr. David Scholl of Moss Landing will be an Associate Principal Investigator. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

The proposed program will use conventional seismic methodology with a single towed GI airgun as the energy source, and a towed hydrophone streamer as the receiver system. The energy to the airguns is compressed air supplied by compressors on board the source vessel.

In addition to the GI gun, bathymetric sonars and an echo sounder will be used during the seismic profiling and continuously when underway. Multi-beam bathymetric and single channel seismic surveys will be conducted prior to scientific rock dredging to ensure that dredging is done as accurately and productively as possible. The surveys will also affect the number of dredges that can be completed. While on station for rock dredging, a 12-kHz pinger will be used to monitor the depth of the dredge relative to the sea floor.

Vessel Specifications

The *Kilo Moana* has a length of 56.5 m, a beam of 26.8 m, and a full load draft of 7.6 m. The *Kilo Moana* is a small water-plane area twin hull (SWATH) vessel. The ship is powered by two 1500-kW Westinghouse motors and two fixed-pitch propellers. Four Caterpillar 3508B 910-kW diesel generators supply power to the ship. The typical operation speed during seismic acquisition will be 16.7 km/h (9 knots). When not towing seismic survey gear, the *Kilo Moana* cruises at 22 km/h (12 knots) and has a maximum speed of 28 km/h (15 knots). It has a normal operating range of about 18,520 km.

The *Kilo Moana* will also serve as the platform from which vessel-based marine mammal observers (MMOs) will watch for mammals and sea turtles before and during GI-gun operations. The characteristics of the *Kilo Moana* that make it suitable for visual monitoring are described in § II(3).

Other details of the *Kilo Moana* include the following:

Owner:	U.S. Navy
Operator:	University of Hawaii
Flag:	United States of America
Launch Date:	17 November 2001
Gross Tonnage:	2500
Echosounders:	EM120 deep-water multi-beam, EM1002 shallow-water multi-beam, Echosounder EA500, HPR418
Acoustic Doppler Current Profiler:	RDI 38kHz Ocean Surveyor
Compressors for Air Guns:	Portable L-DEO compressor, LMF DC, capable of 1000 scfm at 2000 psi
Accommodation Capacity:	48 including ~30 scientists

The *Kilo Moana* will also serve as the platform from which vessel-based marine mammal observers will watch for marine mammals before and during airgun operations. The characteristics of the *Kilo Moana* that make it suitable for visual monitoring are described in § XIII, MONITORING AND REPORTING PLAN.

Airgun Description

The L-DEO portable high-resolution seismic system will be installed on the *Kilo Moana* for this cruise. The source vessel will tow the single GI gun and a streamer containing hydrophones along predetermined lines. Seismic pulses will be emitted at intervals of 5–10 s. The 5–10 s spacing corresponds to a shot interval of ~13–26 m.

The GI gun will have a total discharge volume of up to 105 in^3. The gun will be towed ~44.3 m behind the stern at a depth of about 3 m. The GI gun specifications are shown below.

GI Gun Specifications

Energy source	One GI gun of 105 in^3
Source output (downward)[1]	0-pk is 3.6 bar-m (231 dB re 1 µPa-m);
	pk-pk is 7.0 bar-m (237 dB)
Towing depth of energy source	3 m
Air discharge volume	up to 105 in^3
Dominant frequency components	0–188 Hz

For a one-gun source, the nominal source level represents the actual level that would be found about 1 m from the GI gun. Actual levels experienced by any organism more than 1 m from the GI gun will be significantly lower.

The rms (root mean square) received levels that are used as impact criteria for marine mammals are not directly comparable to the peak or peak-to-peak values normally used to characterize source levels of airguns. The measurement units used to describe airgun sources, peak or peak-to-peak decibels, are always higher than the "root mean square" (rms) decibels referred to in much of the biological literature. A measured received level of 160 decibels rms in the far field would typically correspond to a peak measurement of about 170 to 172 dB, and to a peak-to-peak measurement of about 176 to 178 decibels, *as measured for the same pulse received at the same location* (Greene 1997; McCauley et al. 1998, 2000a). The precise difference between rms and peak or peak-to-peak values depends on the frequency content and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level for an airgun-type source.

The depth at which the source is towed has a major impact on the maximum near-field output, because the energy output is constrained by ambient pressure. The normal tow depth of the source to be used in this project is 3 m, where the ambient pressure is 3 decibars. This also limits output, as the 3 decibars of confining pressure cannot fully constrain the source output, with the result that there is loss of energy at the sea surface.

Additional discussion of the characteristics of airgun pulses is included in Appendix A (c).

Received sound levels have been modeled by L-DEO for the single GI gun in relation to distance and direction from the gun (Fig. 2). The model does not allow for bottom interactions, and is most directly applicable to deep water. Based on the model, the distances from the single GI gun where sound levels of 190, 180, 170, and 160 dB re 1 µPa (rms) are predicted to be received are shown in the >1000 m line of Table 1. The rms (root-mean-square) pressure is an average over the pulse duration. This is the measure commonly used in studies of marine mammal reactions to airgun sounds, and in NMFS guide-lines concerning levels above which "taking" might occur. The rms level of a seismic pulse is typically about 10 dB less than its peak level (Greene 1997; McCauley et al. 1998, 2000a).

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[1] All source level estimates are for a filter bandwidth of approximately 0–250 Hz.

1x105 GI airgun directivity
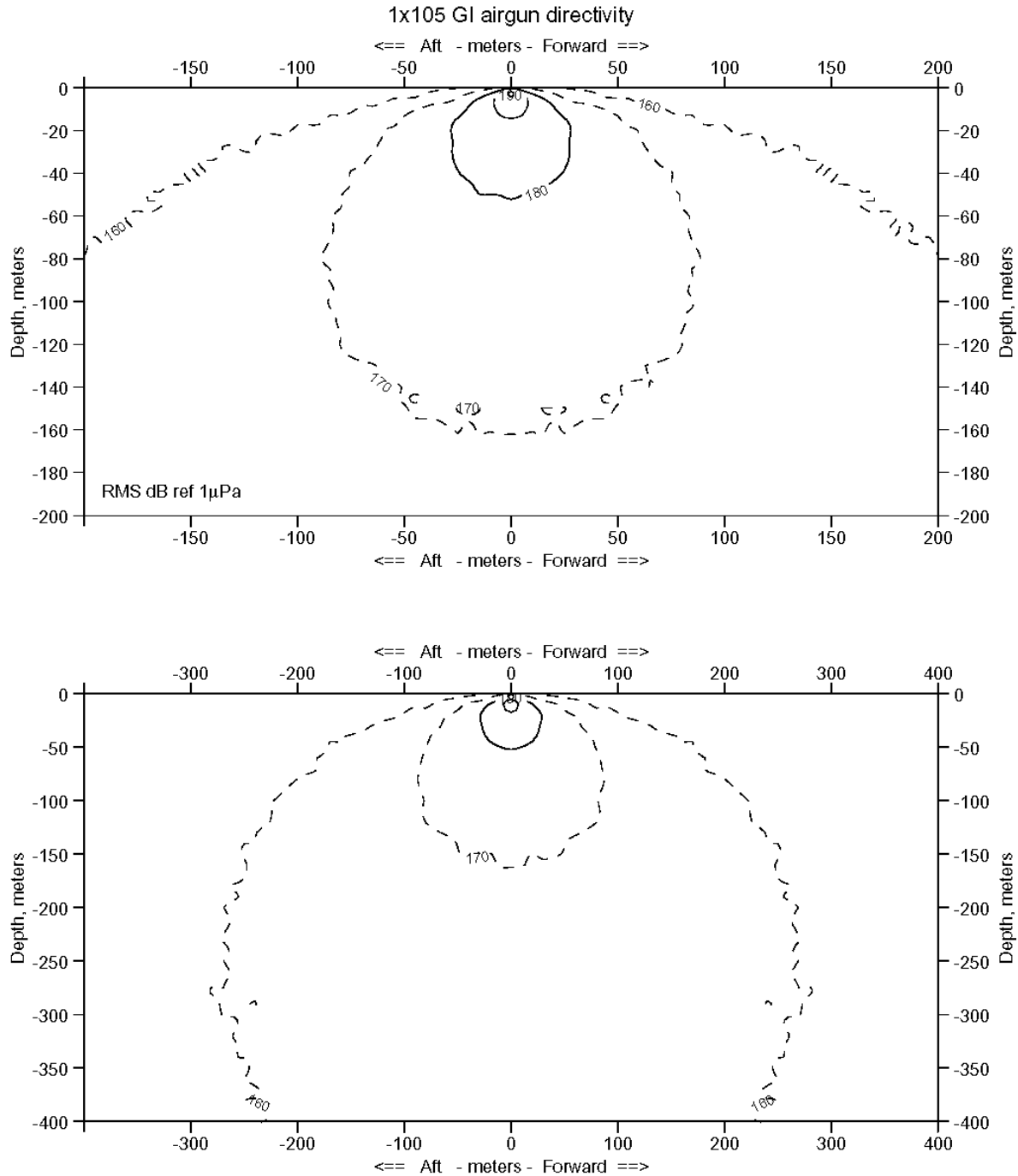
one "GI" airgun 105 x 105 cu. in.   3.6 Bar-m [231 dB] peak

Total Generator vol. 105 cu. in.   7.0 Bar-m [237 dB] P-P

Tow Depth 3.0 m.

FIGURE 2. Modeled received sound levels from the one 105 in³ GI gun that will be used during the L-DEO survey around the Aleutian Islands during 2005. The model does not allow for bottom interactions, so is most directly applicable to deep-water situations.

TABLE 1. Estimated distances to which sound levels ≥190, 180, 170, and 160 dB re 1 µPa (rms) might be received from the one 105 in³ GI gun that will be used during the seismic survey around the Aleutian Islands during 2005. The safety radii used during the survey will depend on water depth (see text).

Water depth	Estimated Distances at Received Levels (m)			
	190 dB	180 dB	170 dB	160 dB
>1000 m	10	27	90	275
100–1000 m	15	41	135	413
<100 m	125	200	375	750

Empirical data concerning the 180, 170, and 160 dB distances have been acquired based on measurements during the acoustic verification study conducted by L-DEO in the northern Gulf of Mexico from 27 May to 3 June 2003 (Tolstoy et al. 2004a,b). Although the results are limited, the data showed that radii around the airguns where the received level would be 180 dB re 1 µPa (rms), the safety criterion applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190 dB distances applicable to pinnipeds. The 180 and 190 dB distances are typically used as safety radii during seismic surveys. The 180 dB distance will be used as the safety radius for cetaceans, and the 190 dB distance will be used for pinnipeds. A precautionary disturbance radius of 160 dB will be used for sea otters (see further in next section). For all turtle sightings, the 180 dB distance will be used as the safety radius. The proposed study area will occur in water ~30–3000 m, although only 3% of the survey lines are expected to occur in shallow (<100 m) water.

- The empirical data indicate that, for **deep water** (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004a,b). However, to be precautionary pending acquisition of additional empirical data, it is proposed that safety radii during GI gun operations in deep water will be the values predicted by L-DEO's model (Table 1). The assumed 190 and 180 dB radii for one GI gun are 10 m and 27 m, respectively.

- Empirical measurements were not conducted for **intermediate depths** (100–1000 m). On the expectation that results will be intermediate between those from shallow and deep water, a 1.5x correction factor is applied to the estimates provided by the model for deep water situations. This is the same factor that was applied to the model estimates during L-DEO cruises in 2003. The assumed 190 and 180 dB radii in intermediate-depth water are 15 m and 41 m, respectively (Table 1).

- Empirical measurements were not made for a single small source operating in **shallow water** (<100 m). However, the measured 180 dB radius for the 6-airgun array operating in shallow water was 6.8x that predicted by L-DEO's model for operation of the 6-airgun array in deep water. This conservative correction factor was used to predict the radii for two GI guns. The radii for one GI gun were assumed to be half of those for the two GI guns. Thus, the 190 and 180 dB radii in shallow water are assumed to be 125 m and 200 m, respectively (Table 1).

Description of Operations

The program will consist of ~4112 km of surveys, not including transits when the GI gun is not operating, plus scientific rock dredging. Water depths within the study area are <50–3500 m. Less than 1% of the survey (31.2 km) will occur in water depths <100 m, 32.8% of the survey (1348.9 km) will be conducted in water 100–1000 m deep, and most (66.4%) of the survey (2731.5 km) will occur in water deeper than 1000 m. There will be additional operations associated with GI gun testing, start up, line changes, and repeat coverage of any areas where initial data quality is sub-standard. Details of the seismic surveys to be conducted are outlined in Table 2.

TABLE 2. Planned total seismic survey lengths and the approximate number of hours required to complete each survey.

Location of Seismic Survey	Survey Length (km) at water depths (m)			Total Survey Length	Time
	<100	100–1000	>1000		
Adak to Buldir	30.8	970.3	1311.9	2313.0	248.7
Bogoslof and Islands of Four Mountains	0	278.3	337.3	615.6	66.2
Near Islands/Attu	0.4	100.3	599.4	700.1	75.3
Transit from 4-Mountain Dredge area to Adak	0	0	482.9	482.9	51.9
Total	**31.2**	**1348.9**	**2731.5**	**4111.6**	**442.1**

The seismic surveys will be used to locate appropriate scientific rock dredging sites. Anticipated rock dredging operations are summarized in Table 3. It is estimated that ~70 dredges will occur during the cruise, ranging from 1 to 15 dredges per site. Dredging operations will be on hard, rocky substrate provided by young volcanic features that will vary from kilometer-scale isolated cones to small extrusions erupted along fault planes cutting structurally complex sea floors. No scientific rock dredging operations will be conducted in water <100 m deep, and most rock dredging will occur in water 400–1800 m deep. Rock dredges will have a swath 1–2 m wide and a few tens of meters long. While on station for rock dredging, a 12-kHz pinger will be used to monitor the depth of the dredge relative to the sea floor.

TABLE 3. Dredging locations and approximate number of dredges to be conducted at each.

Dredging Location	Number of Dredges
Bogoslov	2
Umnak	2
Four Mountains	2
Gareloi	15
Little Sitkin	15
Murray Canyon	1
Buldir	12
Engenstrem	9
Attu	3
Kresta	9

Other Acoustic Sources

Along with the GI gun operations, additional acoustical systems will be operated during much or all of the cruise. The ocean floor will be mapped with a multi-beam sonar, and a hydrographic echo sounder will be used. These two systems are commonly operated simultaneously with a gun array. In addition, other acoustical systems include a 38 kHz ADCP (RDI Ocean Surveyor), which provides vertical profiles of ocean current speed and direction, and an acoustic positioning system (Simrad HPR 418).

Deep-Water Multi-beam Echo Sounder (Simrad EM120)

The Simrad EM120 operates at 11.25 to 12.6 kHz, and is mounted in the port hull of the *Kilo Moana.* It and it operates in several modes, depending on water depth. In the proposed survey, it will be used in deep (>800-m) water, and will operate in "Deep" mode. The beamwidth is 1° or 2° fore-aft and a total of 150° athwartship. Estimated maximum source levels are 239 and 233 dB at 1° and 2° beam widths, respectively. Each "ping" consists of nine successive fan-shaped transmissions, each ensonifying a sector that extends 1° or 2° fore-aft. In the "Deep" mode, the total duration of the transmission into each sector is 15 ms. The nine successive transmissions span an overall cross-track angular extent of about 150 degrees, with 16 ms gaps between the pulses for successive sectors. A receiver in the overlap area between two sectors would receive two 15-ms pulses separated by a 16-ms gap. The "ping" interval varies with water depth, from ~5 s at 1000 m to 20 s at 4000 m.

Shallow-Water Multi-beam Echo Sounder (Simrad EM1002)

The EM1002 is a compact high-resolution multi-beam echo sounder that operates at a frequency of 92 to 98 kHz in water depths from 10 to 800 m. The system operates with one of three different pulse lengths: 0.2, 0.7, and 2 ms. Pulse length increases with increased water depth. Overall angular coverage of the transmitted beam is 3 degrees along the fore-aft axis and 150 degrees along the cross-track axis. The width of coverage is about 1500 m in deeper waters and up to 7.4 times water depth in shallower water. Maximum ping rate is 10/s (in shallow water) with the ping rate decreasing with increasing water depth. Maximum output using long pulses in 800 m water depth is 226 dB re 1 μPa at one meter, and operations in shallower depths use significantly lower output levels.

Hydrographic Echo Sounder (Simrad EA 500)

The EA 500 is a single- or split-beam echo-sounding system with three transducer frequencies: 12, 38, and 200 kHz. Ranges are 13,000 m for 12-kHz operation and 500 m for 200-kHz operation. It has a ping rate of 10 pings/s.

12-kHz Pinger

The 12-kHz Pinger will be used only during scientific rock dredging operations to monitor the depth of the dredge relative to the sea floor. The pinger is a battery-powered acoustic beacon that is attached to the rock dredging mechanism. The pinger produces an omnidirectional 12-kHz signal with a source output of 193 dB re 1 μPa at one meter. The pinger produces a 2-ms pulse every second.

Acoustic Positioning System (Simrad HPR 418)

The Simrad HPR 418 acoustic positioning system uses short- and long-baseline modes to compute location within a network of bottom acoustic transponders. It has two operating ranges, 20–32 kHz in water depths up to 3000 m, and 10–15 kHz in depths up to 6000 m. Its source output varies with depth and operating range, as follows: at 20–32 kHz, 188 dB (typical maximum depth of 1500 m), 195 dB (2000 m), and 206 dB (3000 m); and at 10–15 kHz, 205 dB (6000 m).

II. DATES, DURATION, AND REGION OF ACTIVITY

> The date(s) and duration of such activity and the specific geographical region where it will occur.

The *Kilo Moana* is expected to depart Dutch Harbor, AK, on 14 June 2005. It will take ~2 h to arrive at the study area. The entire cruise will last for ~36 days, and ~30.5 days will be allotted to seismic surveys, scientific rock dredging, and transiting between dredge sites. Three to four days will be spent moving between sites. It is estimated that the total seismic survey time will be ~10.25 days and that scientific rock dredging will take ~20.3 days. It is estimated that ~70 dredges will occur during the cruise, ranging from 1 to 15 dredges per site. Seismic surveys will alternate with scientific rock dredging. The streamer will be recovered at the end of each seismic survey, but may remain deployed between seismic lines when the GI gun may not be firing. The vessel is expected to return to Dutch Harbor on 20 July, after ~5.4 days of transiting.

The seismic and scientific rock dredging survey will take place around the Aleutian Islands (Fig. 1). The overall area within which the seismic survey will occur is located approximately between 51º50' and 54º20'N, and between 172ºE and 166ºW (Fig. 1). The seismic survey will be conducted in the territorial waters and Exclusive Economic Zone (EEZ) of the U.S.A.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

> The species and numbers of marine mammals likely to be found within the activity area.

A total of 18 cetacean species and 10 species of pinnipeds are known to or may occur in the proposed study area around the Aleutian Islands (Table 4). Several of the species are listed as "Endangered" under the ESA, including the humpback, sei, fin, blue, North Pacific right, and sperm whales. Also, the eastern stock of the Steller sea lion is listed under the ESA as "Threatened", and the western stock is listed as "Endangered".

To avoid redundancy, we have included the required information about the species and (insofar as it is known) numbers of these species in Section IV, below.

IV. STATUS, DISTRIBUTION AND SEASONAL DISTRIBUTION OF AFFECTED SPECIES OR STOCKS OF MARINE MAMMALS

> A description of the status, distribution, and seasonal distribution (when applicable) of the affected species or stocks of marine mammals likely to be affected by such activities

Sections III and IV are integrated here to minimize repetition.

The marine mammals that occur in the proposed survey area belong to four taxonomic groups: odontocetes (toothed cetaceans, such as dolphins and sperm whale), mysticetes (baleen whales), pinnipeds (seals, sea lions, and walrus), and fissipeds (sea otter). Of the 18 cetacean species in the area, several are common (see below). Six cetacean species are listed as *Endangered* under the ESA, including the humpback, sei, fin, blue, North Pacific right, and sperm whales.

TABLE 4. The habitat, abundance, and conservation status of marine mammals inhabiting the proposed study area in the Aleutian Islands.

Species	Habitat	Abundance (Alaska)	Regional Abundance	ESA[1]	IUCN[2]	CITES[3]
Odontocetes						
Sperm whale (*Physeter macrocephalus*)	Pelagic, deep seas	159 [9]	24,000 [4]	Endangered*	VU	I
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	N.A.	20,000 [5] 1884 [6]	Not listed	DD	II
Baird's beaked whale (*Berardius bairdii*)	Pelagic	N.A.	6000 [7] 228 [6]	Not listed	LR-cd	I
Stejneger's beaked whale (*Mesoplodon stejnegeri*)	Likely pelagic	N.A	N.A	Not listed	DD	II
Beluga whale (*Delphinapterus leucas*)	Coastal, ice edges	1619 [11] 435 [12]	N.A.	Not listed	VU	II
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	Offshore/ inshore	26,880 [8]	59,274 [6]	Not listed	LR-lc	II
Risso's dolphin (*Grampus griseus*)	Offshore/in-shore, >400m	N.A.	16,066 [6]	Not listed	DD	II
Killer whale (*Orcinus orca*)	Widely distributed	1472 [9]	1340 [6]	Not listed	LR-cd	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Inshore and offshore	N.A.	160,200 [5] 304 [6]	Not listed	LR-cd	II
Harbor Porpoise (*Phocoena phocoena*)	Coastal, inland waters	47,356 [14]	39,586 [10]	Not listed	VU	II
Dall's Porpoise (*Phocoenoides dalli*)	Shelf and pelagic	30,248 [9]	98,617 [6] 417,000 [13]	Not listed	LR-cd	II
Mysticetes						
North Pacific right whale (*Eubalaena japonica*)	Coastal and shelf	N.A.	<100 [15]	Endangered*	EN	I
Gray whale (*Eschrichtius robustus*) (eastern Pacific population)	Coastal, lagoons	N.A.	26,635 [16]	Not listed	LR-cd	I
Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore and banks	2036 [18] 4005 [19] 2866 [9]	>6000 [17]	Endangered*	VU	I
Minke whale (*Balaenoptera acutorostrata*)	Shelf, coastal	1512 [9]	1015 [6] 810-1003 [20]	Not listed	LR-cd	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	N.A.	7260-12,620 [21,22] 56 [6]	Endangered*	EN	I
Fin whale (*Balaenoptera physalus*)	Slope, mostly pelagic	N.A.	8520-10,970 [21,23] 3279 [6]	Endangered*	EN	I
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	N.A.	1400-1900 [24] 3000 [25]	Endangered*	EN	I
Pinnipeds						
Northern fur seal (*Callorhinus ursinus*)	Pelagic, breeds coastally	N.A.	888,120 [26]	Not listed but depleted	VU	N.A.
California sea lion (*Zalophus californianus*)	Coastal, shelf	N.A.	244,000-237,000 [27]	Not listed	NA	NA
Steller sea lion (*Eumetopias jubatus*)	Coastal	34,779 [13]	31,028 [26]	Threatened† Endangered‡	EN	N.A.
Pacific Walrus (*Odobenus rosmarus divergens*)	Ice	N.A.	201,039 [28]	Not listed	N.A.	N.A.
Bearded seal (*Erignathus barbatus*)	Ice	N.A.	300,000 [29]	Not listed	N.A.	N.A.

Species	Habitat	Abundance (Alaska)	Regional Abundance	ESA[1]	IUCN[2]	CITES[3]
Harbor seal (*Phoca vitulina richardsi*)	Coastal	29,175 [30]	N.A.	Not listed	N.A.	N.A.
Spotted seal (*Phoca largha*)	Ice	N.A.	250,000 [31]	Not listed	N.A.	N.A.
Ringed seal (*Pusa hispida*)	Ice	N.A.	Up to 3.6 million [32]	Not listed	N.A.	N.A.
Ribbon seal (*Histriophoca fasciata*)	Ice	N.A.	100,000 [33]	Not listed	N.A.	N.A.
Northern elephant seal (*Mirounga angustirostris*)	Coastal, pelagic when migrating	N.A.	101,000 [34]	Not listed	NA	NA.

N.A. means data not available.

[1] Endangered Species Act

[2] IUCN Red List of Threatened Species (2003). Codes for IUCN classifications: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened; -lc = Least Concern); DD = Data Deficient.

[3] Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2004).

[4] Abundance estimate for eastern temperate North Pacific (Whitehead 2002).

[5] Abundance in the Eastern Tropical Pacific (Wade and Gerrodette 1993).

[6] Abundance off California/Oregon/Washington (Barlow 2003).

[7] Abundance in Western North Pacific (Reeves and Leatherwood 1994).

[8] Abundance estimate for GOA (Buckland et al. 1993a).

[9] Northern GOA and Aleutian Islands (Zerbini et al. 2004).

[10] Oregon/Washington stock (Carretta et al. 2004).

[11] Bristol Bay stock (Angliss and Lodge 2004).

[12] Abundance estimate for Cook Inlet stock (Hobbs et al. 2000).

[13] Abundance estimate for western stock (Angliss and Lodge 2004).

[14] Abundance estimate for Bering Sea stock (Angliss and Lodge 2004).

[15] Eastern populations (Carretta et al. 2002).

[16] Abundance estimate for eastern Pacific (Hobbs and Rugh 1999).

[17] North Pacific (Calambokidis and Barlow 2004).

[18] All feeding aggregations (Angliss and Lodge 2004).

[19] Abundance estimate for the central North Pacific stock (Calambokidis et al. 1997).

[20] Abundance estimate for Bearing Sea (Moore et al. 2002b).

[21] USWC (Carretta et al. 2004).

[22] Abundance in NPO (Tillman 1977).

[23] Abundance in NPO (Ohsumi and Wada 1974).

[24] Abundance in NPO (Klinowska 1991).

[25] Abundance for California/Oregon/Washington (Calambokidis and Barlow 2004).

[26] Abundance for eastern NPO or eastern stock (Angliss and Lodge 2004).

[27] Abundance estimate for SE Alaska stock (Angliss and Lodge 2004).

[28] Estimate for population in 1990 (Gilbert et al. 1992 *in* Angliss and Lodge 2004); current size unknown.

[29] Estimate for Bering Sea (Burns 1981a); current estimate is unavailable.

[30] Abundance estimate for the GOA stock (Angliss and Lodge 2004).

[31] Estimate for Bering Sea (Burns 1973); current estimate is unavailable.

[32] Alaska estimate (Frost et al. 1988 *in* Angliss and Lodge 2004).

[33] Estimate for Bering Sea (Burns 1981b); current estimate is unavailable.

[34] California Breeding Stock (Carretta et al. 2004)

* Listed as a strategic stock under the U.S. Marine Mammal Protection Act.

† Eastern stock; listed as a strategic stock under the U.S. Marine Mammal Protection Act.

‡ Western stock; listed as a strategic stock under the U.S. Marine Mammal Protection Act.

Four species of pinnipeds potentially could occur in the western Aleutian Islands, including Steller sea lions, harbor seals, northern fur seals, and ribbon seals. Numbers of Steller sea lions, harbor seals, northern fur seals, and sea otters have been decreasing in the North Pacific region in the last several decades (Springer et al. 2003). Although causes of the declines are poorly understood, it is evident that incidental mortality attributable to commercial fisheries and intentional harvesting during the 1960s and 1970s have played a role in the initial declines, and that predation by killer whales is a contributing factor (Springer et al. 2003). The eastern stock of the Steller sea lion is listed under the ESA as ***Threatened***, and the western stock is listed as ***Endangered***. A formal Section 7 consultation will be conducted with NMFS regarding Steller sea lions and operations in the project area.

The walrus, California sea lion, and ringed, spotted, bearded, and northern elephant seals likely will not be encountered in the study area although they are known to occur in the eastern Aleutians. The sea otter and the walrus are the two marine mammal species mentioned in this document that, in the U.S., are managed by the USFWS; all others are managed by NMFS. A conference will also be conducted with the USFWS regarding project operations and sea otters. Walruses are unlikely to be encountered in the proposed study area.

Few surveys have examined the distribution and abundance of marine mammals inhabiting the waters around the Aleutian Islands, although a few reports are available (e.g., Forney and Brownell 1996; Moore 2001; Wade et al. 2003).

Odontocetes

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). They range as far north and south as the edges of the polar pack ice, although they are most abundant in tropical and temperate waters where temperatures are >15ºC or 59ºF (Rice 1989). In the North Pacific Ocean, sperm whales are distributed widely, with the northernmost occurrences at Cape Navarin (62ºN) and the Pribilof Islands (Omura 1955). Sperm whales generally occur in deep water, over and beyond the continental slope.

During surveys in the Aleutian Islands in 1996, the sperm whale was the second most common large whale (Forney and Brownell 1996). Twelve sightings were made, most of them in deep (4000–5000 m) water over the Aleutian Abyssal Plain and north over the Aleutian Trench over deep basins (Forney and Brownell 1996). During summer surveys extending from the Kenai Fjord to the central Aleutian Islands in 2001–2003, 37 sightings of 44 sperm whales were made; the mean group size was 1.2 (Wade et al. 2003). During a survey in the eastern Aleutian Islands June 2001, Moore (2001) noted that sperm whales were common north of Seguam Island and in Seguam Pass. The estimated annual mortality or serious injury from longline fishing is 0.4 (Angliss and Lodge 2004). During the Splash 2004 Cruise from 12 to 25 August, 18 sperm whales were seen throughout the Aleutian Islands (Barlow 2004a,b). Zerbini et al. (2004) estimated the abundance of sperm whales in the northern GOA and Aleutian Islands at 159.

Sperm whales generally are distributed over large areas that have high secondary productivity and steep underwater topography (Jacquet and Whitehead 1996). They routinely dive to depths of hundreds of meters and may occasionally dive to depths of 3000 m or 9843 ft (Rice 1989). They are capable of remaining submerged for longer than two hours, but most dives probably last 30 min or less (Rice 1989).

Sperm whales occur singly (older males) or in groups of up to 50. Christal et al. (1998) noted that typical social unit sizes ranged from 3 to 24. Sperm whale distribution is thought to be linked to social structure. Adult females and juveniles generally occur in tropical and subtropical waters, whereas males are commonly alone or in same-sex aggregations, often occurring in higher latitudes outside of the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Males may migrate north in the summer to feed in the GOA, Bering Sea, and waters around the Aleutian Islands (Angliss and Lodge 2004). Mature sperm whales begin to migrate to warmer waters to breed when they are in their late twenties (Best 1979), returning to colder waters to feed after the breeding season. They typically move between mixed schools, and only spend a short period of time with them (Whitehead 1993). Sperm whales are seasonal breeders, but the mating season is prolonged. In the Northern Hemisphere, conception may occur from January to August (Rice 1989), although the peak breeding season is April–June (Best et al. 1984). Females bear a calf every 3–6 years (Rice 1989).

Sperm whales produce acoustic clicks when underwater, probably for locating prey and communicating (Backus and Schevill 1966; Møhl et al. 2003). In the Galapagos Islands, sperm whales started to click regularly when they were 150–300 m deep (Papastavrou et al. 1989), which may indicate that the sperm whales were echolocating for food at those depths (Backus and Schevill 1966; Weilgart and Whitehead 1988; Smith and Whitehead 1993). On the breeding grounds, mature males produce "slow clicks" (Whitehead 1993) in the frequency range 0.1–30 kHz (review by Thomson and Richardson 1995).

Commercial whaling severely reduced the abundance of sperm whales. Whitehead (2002) estimated that the worldwide stock was 32% of its original level in 1999, ten years after the end of large-scale hunting. The sperm whale is the only species of odontocete discussed here that is listed under the ESA, and the only species of odontocete that is listed in CITES Appendix I (Table 4). Although the species is formally listed as ***Endangered*** under the ESA, it is a relatively common species on a worldwide basis, and is not biologically endangered.

Baird's Beaked Whale (*Berardius bairdii*)

Baird's beaked whales have a fairly extensive range across the North Pacific, north of 35°N, with concentrations apparently occurring in the Sea of Okhotsk and Bering Sea (Rice 1998; Kasuya 2002). Strandings have occurred as far north as the Pribilof Islands (Rice 1986). There are numerous sighting records from the mid GOA, the Aleutian Islands, and the southern Bering Sea (Kasuya and Ohsumi 1984). Baird's beaked whales may be divided into three distinct stocks: Sea of Japan, Okhotsk Sea, and Bering Sea/eastern North Pacific (Balcomb 1989; Reyes 1991).

Little is known about the abundance of Baird's beaked whales in the proposed study area. A total of 8 sightings of 86 Baird's beaked whales were made during summer surveys extending from the Kenai Fjord to the central Aleutian Islands in 2001–2003; the mean group size was 10.8 (Wade et al. 2003). One of these groups was seen on the north side of Tanaga Island (Wade et al. 2003). Forney and Brownell (1996) made one sighting of Baird's beaked whale during surveys in the Aleutians in 1994 in deep (4000–5000 m) water. Moore et al. (2002b) documented a sighting of 18 Baird's beaked whales in the southeastern Bering Sea (SEBS). Leatherwood et al. (1983) reported a sighting of a Baird's beaked whale by Umnak Island, and summarized previous sightings in the area. Brueggeman et al. (1987) noted the occurrence of Baird's beaked whales during aerial surveys in 1985 in the northwestern GOA. An estimated 6000 animals are thought to occur in the western North Pacific (Reeves and Leatherwood 1994; Kasuya 2002).

Baird's beaked whales sometimes are seen close to shore, but their primary habitat is over or near the continental slope and oceanic seamounts in waters 1000–3000 m deep (Jefferson et al. 1993). Baird's

beaked whales live in pods of 5 to 20, although larger groups are sometimes seen. There appears to be a calving peak in March and April (Jefferson et al. 1993).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

This cosmopolitan species is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). It appears to be absent from areas north of 60ºN and south of 50ºS (Würsig et al. 2000). Cuvier's beaked whales range north to the northern GOA, including SE Alaska, the Aleutian Islands, and the Commander Islands (Rice 1986, 1998). No reliable estimates are available for the Alaska population (Angliss and Lodge 2004). They are considered rare in the Aleutian Islands. Leatherwood et al. (1983) noted the occurrence of Cuvier's beaked whales in the eastern Aleutian Islands and summarized sightings there. One sighting was made during surveys in the Aleutians in 1994 in deep (4000–5000 m) water (Forney and Brownell 1996). Cuvier's beaked whales were also seen during 1985 surveys in the northwestern GOA (Brueggeman et al. 1987). During the Splash 2004 Cruise from 12 to 25 August, one unidentified Ziphiid whale was seen in the Aleutian Islands (Barlow 2004b).

Cuvier's beaked whales are rarely found close to mainland shores, except in submarine canyons or in areas where the continental shelf is narrow and coastal waters are deep (Carwardine 1995). Mostly pelagic, they appear to be confined to waters warmer than 10°C and deeper than 1000 m (Houston 1991; Robineau and di Natale 1995). Cuvier's beaked whales typically dive for 20–40 min. Their inconspic-uous blows, deep-diving behavior, and tendency to avoid vessels may help explain the rarity of sightings. Adult males usually travel alone, but Cuvier's beaked whales can be seen in groups of up to 25 individuals. Calves appear to be born year-round (Würsig et al. 2000).

Cuvier's beaked whale is mostly known from strandings (Leatherwood et al. 1976; NOAA and USN 2001). There are more recorded strandings for Cuvier's beaked whale than for any other beaked whale (Heyning 1989). Causes of most strandings are unknown, but they likely include old age, illness, disease, pollution, exposure to certain strong noises, and perhaps geomagnetic disturbance. Mass strandings of Cuvier's beaked whales are rare (although individual strandings are quite common), with only seven documented cases of more than four individuals stranding between 1963 and 1995 (Frantzis 1998). Several additional mass strandings have been documented subsequently in association with sources of strong noise (see § IV).

Stejneger's Beaked Whale (*Mesoplodon stejnegeri*)

Stejneger's beaked whale is endemic to the cold waters of the North Pacific, Sea of Japan, and Bering Sea (Angliss and Lodge 2004). It is the only mesoplodont species known to occur in Alaskan waters, and it occurs from SE Alaska through to the Aleutian Islands, the central Bering Sea, and the Pribilof and Commander Islands.

There are currently no reliable estimates of the abundance of the Alaskan stock of Stejneger's beaked whale (Angliss and Lodge 2004). However, Stejneger's beaked whales are considered uncommon in the Aleutian Islands. Leatherwood et al. (1983) summarized sightings in the eastern Aleutians. A sighting of two unidentified beaked whales, possibly Stejneger's beaked whales, was made on the south side of Unalaska Island during surveys in 2002 (Wade et al. 2003). During the Splash 2004 Cruise from 12 to 25 August, one *Mesoplodon* sp. and one Ziphiid whale were seen in the Aleutian Islands (Barlow 2004b). In the past, groups of 3–15 Stejneger's beaked whales have been sighted on occasion near the central Aleutian Islands (Rice 1986).

Beluga Whale (*Delpinapterus leucas*)

Beluga whales are distributed in seasonally ice-covered seas throughout the Northern Hemisphere (Gurevich 1980). In Alaska, beluga whales comprise five distinct stocks: Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet (O'Corry-Crowe et al. 1997). It is assumed that all of the stocks, other than the Cook Inlet stock, overwinter in the Bering Sea and are segregated only during the summer (Shelden 1994). None of the stocks occur regularly in the proposed study area, although extralimital animals could be encountered. For example, Leatherwood et al. (1983) saw a beluga just north of the Unalaska Island in July 1982.

The minimum population estimate for the Bristol Bay stock is 1619 (Angliss and Lodge 2004). Estimates of the size of the Cook Inlet beluga population over the last several decades have ranged from 300 to 1300 whales. Subsistence hunting of beluga whales occurs throughout Alaska. In addition, belugas are occasionally taken incidentally in the commercial fishery, especially in the Bristol Bay gillnet fishery, at a minimum annual mortality =0.5 (Angliss and Lodge 2004).

Pod structure in beluga groups appears to be along matrilineal lines, with males forming separate aggregations. Small groups are often observed traveling or resting together. The relationships between whales within groups are not known, although hunters have reported that belugas form family groups with whales of different ages traveling together (Huntington 2000).

Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*)

The Pacific white-sided dolphin is found throughout the temperate North Pacific, north of the coasts of Japan and Baja California Sur (Rice 1998). In the eastern North Pacific, it occurs north into the GOA and west to Amchitka in the Aleutian Islands, but rarely in the southern Bering Sea (Angliss and Lodge 2004). Two stocks are identified in North America: the North Pacific and the California/Oregon/ Washington stocks (Angliss and Lodge 2004).

Pacific white-sided dolphins are considered rare in the Aleutian Islands and are unlikely to be encountered in the proposed study area. However, during summer surveys extending from the Kenai Fjord to the central Aleutian Islands in 2001–2003, one group of 8 Pacific white-sided dolphins was seen (Wade et al. 2003). Moore et al. (2002b) documented a group of 8 dolphins in the SEBS along the Alaska Peninsula. Pacific white-sided dolphins are occasionally taken incidentally by commercial fishing operations, with a minimum total annual mortality rate of 3.05 (Angliss and Lodge 2004).

Buckland et al. (1993a) estimated a total population of 931,000 Pacific white-sided dolphins, rangewide, from surveys conducted in the North Pacific. While there have been no comprehensive surveys for Pacific white-sided dolphins in Alaska, the portion of the Buckland et al. (1993a) estimate derived from GOA waters (26,880) is used as an estimate of the population size in the GOA (Angliss and Lodge 2004).

Pacific white-sided dolphins are common both on the high seas and along the continental margins, and are known to enter the inshore passes of SE Alaska, British Columbia, and Washington (Leatherwood et al. 1984; Dahlheim and Towell 1994; Ferrero and Walker 1996). Dahlheim and Towell (1994) encountered 85–1331 Pacific white-sided dolphins during their surveys through inland waters of SE Alaska in 1991–1993. Some seasonal shifts in distribution are known to occur, in rough synchrony with movements of prey (Leatherwood et al. 1984).

Pacific white-sided dolphins form large herds averaging 90 dolphins per group, but groups of more than 3000 are known (Van Waerebeek and Würsig 2002). Pacific white-sided dolphins are acrobatic and frequently approach vessels to "bow ride" (Van Waerebeek and Würsig 2002).

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species that is distributed worldwide. It is pelagic, mostly occurring in steep, shelf edge habitats in waters 400 to 1000 m deep (Baumgartner 1997; Davis et al. 1998a). The species occurs between 60ºN and 60ºS, where surface water temperatures range from ~7.5 to 35ºC (Kruse et al. 1999).

Risso's dolphins occur individually or in groups normally ranging from 2 to <250 animals, although groups as large as 4000 have been sighted (Baird 2002). The majority of groups consist of <50 (Kruse et al. 1999). They use sounds that range from 0.1 to 8 kHz and ultrasounds up to 65 kHz (review by Thomson and Richardson 1995).

In California, increasing numbers of Risso's dolphins, and a shoreward shift in their distribution, have been observed during periods of warm water (Kruse et al. 1999). Barlow (2003) estimated the abundance of Risso's dolphin off California/Oregon/Washington at 16,066, from surveys conducted in 1996 and 2001. Surveys for Risso's dolphins have not been conducted in Alaska. This species is unlikely to be seen in the proposed study area.

Killer Whale (*Orcinus orca*)

Killer whales are cosmopolitan, occurring from equatorial regions to the polar pack-ice, and are fairly abundant globally. They are most common in high latitudes, especially in cooler areas where productivity is high. The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975). Killer whales are known to inhabit almost all coastal waters of Alaska, extending from the Chukchi and Bering Seas, along the Aleutian Islands to the GOA and SE Alaska.

Killer whales are segregated socially, genetically, and ecologically into three distinct groups: residents, transients, and offshore animals. Resident groups feed exclusively on fish, whereas transients feed exclusively on marine mammals. Offshore killer whales are less known, and their feeding habits are not strictly defined, although they are thought to feed on fish (Wade et al. 2003). Killer whale movements generally appear to follow the distribution of prey.

All three ecotypes of killer whales have been seen in the Aleutian Islands (Wade et al. 2003). During recent surveys from the Kenai Fjords to the central Aleutian Islands (just west of Tanaga Island), numerous sightings of killer whales were made (Wade et al. 2003). The survey documented the most westerly killer whale sightings in U.S. waters, in the western extreme of the survey area in Amchitka Pass (Wade et al. 2003). Over 3 years, a total of 59 groups were seen, totaling 1038 individuals (Wade et al. 2003). The groups ranged in size from 2 to 90, with a median group size of 12 (Wade et al. 2003). Of the 59 groups, 39 (66%) were resident, 14 (24%) were transient, 2 (3%) were offshore, and 4 (7%) were unknown (Wade et al. 2003). Wade et al. (2003) noted that offshore killer whales had the greatest mean group size (50), followed by residents (22) and transients (5).

Relatively high densities of killer whales were found in Seguam Pass and waters around Umnak and Unalaska Islands, as well as Kodiak Island (Wade et al. 2003). The ecotypes seen during surveys appeared to have different distributions; with transients more frequently seen from Shumagin Islands to the eastern Aleutian Islands, and resident killer whales more abundant around Umnak and Unalaska Islands and Kodiak Island (Wade et al. 2003). Sightings of offshore killer whales were made near Kodiak

Island and just outside of Dutch Harbor, Unalaska Island (Wade et al. 2003). These sightings represent the farthest west that offshore killer whales have been encountered (Wade et al. 2003). During the Splash 2004 cruise from 12 to 25 August, a total of 18 killer whales were seen in the Aleutian Islands; the majority were thought to be resident whales, and a small percentage were assumed to be transients (Barlow 2004a,b). Three of the killer whales were seen harassing and killing a Dall's porpoise (Barlow 2004b).

Forney and Brownell (1996) also made sightings (16) of killer whales during surveys just south of the Aleutian Islands in 1994; they were mainly seen in deep waters over the Aleutian Trench and the Aleutian Abyssal Plain. Moore (2001) noted concentrations of killer whales southwest of Unimak Pass and north of Seguam Island. Zerbini et al. (2004) estimated the abundance of killer whales in the northern GOA and Aleutian Islands at 1472. During surveys in the central-eastern Bering Sea (CEBS) and SEBS, 14 sightings of 61 killer whales were made, mostly in the SEBS (Moore et al. 2002b).

Recently, the AT1 group of transient killer whales in Prince William Sound (PWS) has been designated as a separate and depleted stock, pursuant to the MMPA (NOAA 2004a). AT1 killer whales have been recognized in PWS and Resurrection and Aialike bays since at least 1978 (Leatherwood et al. 1984; Saulitas 1993), and are known to occur from PWS to Kenai Fjords. The AT1 group once had as many as 22 members, but was reduced to 9 members after the *Exxon Valdez* Oil Spill. No new calves have been observed since the AT1 group was recognized in 1984. Members of this pod are not expected to be encountered in the proposed study area.

Killer whales often travel in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Sightings range from the surf zone to the open sea, although usually within 800 km of shore. Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999; Springer et al. 2003).

Killer whales are capable of hearing high-frequency sounds, which is related to their use of high-frequency sound for echolocation (Richardson 1995). They produce whistles and calls in the frequency range of 0.5–25 kHz (review by Thomson and Richardson 1995), and their hearing ranges from below 500 Hz to 120 kHz (Hall and Johnson 1972; Szymanski et al. 1999).

Killer whales are occasionally taken incidentally in the commercial fishery; estimated total annual mortality rate is 1.4 (Angliss and Lodge 2004).

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale can be found in tropical and warm temperate waters (Leatherwood and Reeves 1983; Bernard and Reilly 1999), and it is a vagrant visitor to colder waters as far north as the Alaska Peninsula. The short-finned pilot whale is mainly pelagic and occurs in moderately deep waters (Davis et al. 1998a). It is usually found in waters with a depth of ~1000 m, where it feeds on squid. It is generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson and Reilly 2002). Changes in the distribution of the short-finned pilot whale are likely influenced by the distribution of its prey. The species is very social and is usually seen in large groups of up to 60, and is known to strand frequently. Pilot whale pods are composed of individuals with matrilineal associations (Olson and Reilly 2002). This species produces whistles with dominant frequencies of 2–14 kHz (review by Thomson and Richardson 1995). It is not likely to be encountered in the planned survey area.

Harbor Porpoise (*Phocoena phocoena*)

The harbor porpoise is a small odontocete that inhabits temporal, subarctic, and arctic waters. There is also an isolated, remnant population in the Black Sea. In the eastern North Pacific, the harbor porpoise ranges from Point Barrow, Alaska, to Point Conception, California. In Alaska, there are three separate stocks: Southeast Alaska, Gulf of Alaska, and Bering Sea. Porpoises of the Bering Sea stock may occur throughout the proposed study area. The abundance estimate for the Bering Sea stock is 47,356 animals (Angliss and Lodge 2004). During summer surveys extending from the Kenai Fjord to the central Aleutian Islands in 2001–2003, 19 sightings of 34 harbor porpoises were made (Wade et al. 2003). Densities in the CEBS and SEBS were 0.0035 and 0.012/km^2, respectively, and abundance was estimated at 693 and 1959 for the two areas, respectively (Moore et al. 2002b). The authors did not correct for 1) animals missed on trackline, 2) submerged animals, or 3) response movement. During surveys in the CEBS and SEBS, Moore et al. (2002b) documented 68 sightings of 89 individuals. They are occasionally taken incidentally during commercial fishery operations, with a minimum annual mortality ≥1.6 (Angliss and Lodge 2004).

Harbor porpoises have small, stocky bodies that help limit heat loss in cold northern waters. They primarily inhabit coastal waters, although sightings have been made over deeper waters between land masses (Bjørge and Tolley 2002). Harbor porpoises surface quickly, rarely leaping out of the water. They are normally found in small groups of up to 3 that often contain at least one mother-calf pair. Larger groups of 6–8 are not uncommon, and rarely, much larger aggregations are seen. Wade et al. (2003) noted a mean group size of 1.8 in the Aleutians, and Moore et al. (2002b) noted group sizes of 1.0 and 1.3 in the CEBS and SEBS, respectively. Sightings of harbor porpoise in the Aleutians will likely be less frequent than those for Dall's porpoise, given the tendency for harbor porpoises to have a more coastal distribution along with differences in the reactions of the two species to vessels.

Dall's Porpoise (*Phocoenoides dalli*)

Dall's porpoises are only found in the North Pacific and adjacent seas. They are widely distributed across the North Pacific Ocean over the continental shelf and slope waters, and over deep (>2500 m) oceanic waters (Hall 1979). Their distribution extends from southern California and southern Japan to ~65°N (Buckland et al. 1993a). They are abundant in the CEBS and SEBS (Moore et al. 2002b). The only apparent gaps in distribution in Alaskan waters south of Bering Strait are upper Cook Inlet and the Bering Sea shelf.

Dall's porpoises are considered common in the nearshore waters of the Aleutian Islands, and were the most frequently encountered cetacean during surveys in the Aleutians in 1994 (Forney and Brownell 1996). Forney and Brownell (1996) made 151 sightings of Dall's porpoise. During summer surveys extending from the Kenai Fjord to the central Aleutian Islands in 2001–2003, 592 sightings of 2072 Dall's porpoises were made; the mean group size was 3.5 (Wade et al. 2003). During surveys of the central Aleutian Islands, Moore (2001) noted that they were particularly common near Samalga Pass. During surveys in the CEBS and SEBS, Moore et al. (2002b) documented 143 sightings of 447 individuals. The density estimates for the CEBS and SEBS were 0.073 and 0.062/km^2, respectively, and abundance was estimated at 14,312 and 9807, respectively (Moore et al. 2002b). Zerbini et al. (2004) estimated their abundance in the northern GOA and Aleutian Islands at 30,248. However, Turnock and Quinn (1991) suggested that the tendency of this species to approach vessels has resulted in inflated abundance estimates, perhaps by as much as 5 times. Dall's porpoises are incidentally killed during commercial fishing operations, with a minimum annual mortality ≥37.5 (Angliss and Lodge 2004).

Dall's porpoises are most commonly found in small groups of 20 to 30; larger groups of several hundred to ~1000 are rarely seen. Moore et al. (2002b) noted average group sizes of 3.7 and 2.7 in the CEBS and SEBS, respectively. Very little is known about group structure, except that group composition is probably fluid (Jefferson 2002). They are fast-swimming and active porpoises, and readily approach vessels to ride the bow wave. They have also been seen to "snout ride" (Jefferson 2002) the wave pushed forward by the heads of large whales. They are often seen traveling quickly along the surface, creating a V-shaped splash known as a rooster tail. Dall's porpoises calve in the summer, but some calves probably are born outside that season. Gestation lasts ~10–12 months, and lactation lasts up to a year.

Mysticetes

North Pacific Right Whale (*Eubalaena japonica*)

The North Pacific right whale is ***Endangered*** under the ESA, and was considered by NMFS (1991) to be the most endangered baleen whale in the world. Although protected from commercial whaling since 1935, there has been little indication of recovery. The pre-exploitation stock may have exceeded 11,000 (NMFS 1991). Based on sighting data, Wada (1973) estimated a total population of 100–200 in the North Pacific. Rice (1974) stated that only a few individuals remained in the eastern North Pacific stock. A reliable estimate of abundance is not available, but is likely less than 100.

Whaling records indicate that right whales in the North Pacific once ranged across the entire North Pacific north of 35ºN, and occasionally occurred as far south as 20ºN. In the eastern North Pacific, south of 50ºN, only 29 reliable sightings were recorded from 1900 to 1994 (Scarff 1986, 1991; Carretta et al. 1994), and one was recorded in 1996 off Baja, California (Gendron et al. 1999). There have been several sightings of right whales in the North Pacific in recent years, mostly in the southeastern Bering Sea, in Bristol Bay (Angliss and Lodge 2004). In 1996, a group of 3 to 4 right whales that may have included a juvenile was seen in western Bristol Bay (Goddard and Rugh 1998). During July 1997, a group of at least five was seen in Bristol Bay (Tynan 1998). During July 1998, 1999, and 2000, 5, 6, and 13 animals, respectively, were seen in the Bristol Bay area (LeDuc et al. 2001), and in 2002, seven were seen in the SEBS (Angliss and Lodge 2004). Moore et al. (2002b) noted one sighting of two whales in 1999 in the SEBS. During photographic surveys from 1998 to 2000, only 14 individuals were photographed, but at least two whales were photographed in more than one year; this is indicative of a very small population (Angliss and Lodge 2004). All recent sightings of right whales in Alaskan waters have occurred in Bristol Bay, with the exception of one right whale seen south of Kodiak Island in 1998 (Waite et al. 2003), even though surveys have been conducted outside the Bristol Bay area (e.g., Moore et al. 2000, 2002b).

The verified Kodiak Island sighting in 1998 precipitated an acoustic detection study (Mellinger et al. 2004). Two hydrophones were deployed in May 2000, one at the Kodiak sighting location and the other further offshore near the base of the continental slope. The two units complemented an array of five hydrophones installed well offshore in the Gulf of Alaska. Data from the instruments, all recovered by August 2001, were analyzed for North Pacific right whale calls with the use of software, and 12 right whale calls were detected. They were from locations where North Pacific right whales had been sighted only once in decades (the 1998 Kodiak sighting) despite significant visual survey effort. No North Pacific right whales were seen in over 28,700 km surveyed in the GOA or south of the Aleutians during summer aerial and shipboard surveys for large cetaceans (Rice and Wolman 1982; Stewart et al. 1987; Forney and Brownell 1996; Wade et al. 2003; Mellinger et al. 2004).

North Pacific right whales summer in the northern North Pacific and Bering Sea, apparently feeding off southern and western Alaska from May to September (e.g., Tynan et al. 2001). The wintering areas for the population are unknown, but have been suggested to include the Hawaiian Islands and the Ryukyu Islands (Allen 1942; Banfield 1974; Gilmore 1978; Reeves et al. 1978; Herman et al. 1980). In April 1996, a right whale was sighted off Maui, the first documented sighting of a right whale in Hawaiian waters since 1979 (Herman et al. 1980; Rowntree et al. 1980). Historical records indicate that whalers took right whales in Baja California, as far south as the Bay of San Sebastian Viscaino, and near Cerros Island (Scammon 1968). Two right whales were observed east of Guadalupe Island in April 1856, and another two were observed south of Punta Abreojos in March 1965.

Considering the rarity of right whale sightings, and the generally restricted area in which sightings in Alaska have been made, it is highly unlikely that any right whales will be seen during the proposed surveys.

Gray Whale (*Eschrichtius robustus*)

The eastern Pacific population of the gray whale ranges from the Bering, Chukchi, and Beaufort seas (in summer) to the Gulf of California (in winter) (Rice 1998). Gray whales are found primarily in shallow water, and usually remain closer to shore than any other large cetacean. Most of the eastern Pacific population makes a round-trip annual migration of more than 18,000 km. From late May to early October, the majority of the population concentrates in the northern and western Bering Sea and the Chukchi Sea. However, some individuals spend the summer months scattered along the coasts of SE Alaska, British Columbia, Washington, Oregon, and northern California (Rice and Wolman 1971; Darling 1984; Nerini 1984; Calambokidis et al. 2002).

Gray whales are considered common in the nearshore waters of the eastern Aleutian Islands. Twenty-two gray whale sightings of 123 individuals were seen during summer (July–August) surveys in 2001–2003 from the Kenai Peninsula to the central Aleutian Islands (Wade et al. 2003). The mean group size was 5.6 (Wade et al. 2003). In June 2001, a group of ~30 killer whales was seen feeding on a gray whale carcass in Unimak Pass (Wade et al. 2003). During surveys in the CEBS and SEBS, Moore et al. (2002b) encountered 12 groups totaling 24 individuals, mostly in the SEBS close to land. During aerial surveys in the northwestern GOA and SEBS in 1985, Brueggeman et al. (1987) sighted most gray whales during the migration periods in April and November–December; only a few whales were seen in the area during summer.

Gray whales leave the Bering Sea through Unimak Pass from late October through January (Braham 1984). From October to January, the main part of the population moves down the west coast of North America. Rugh et al. (2001) analyzed data collected from two sites in California to estimate the timing of the gray whale southward migration. They estimated that the median date for the migration past various sites was 1 December in the central Bering Sea (a nominal starting point), 12 December at Unimak Pass, 18 December at Kodiak Island, and 5 January for Washington. By January and February, most of the whales are concentrated in lagoons along the Pacific coast of the Baja Peninsula, Mexico. From late February to June, the population migrates northward to arctic and subarctic seas (Rice and Wolman 1971).

Gray whales have been counted as they migrate southward past Granite Canyon in central California each year since 1967. The highest population estimate (26,635) was derived from counts during the 1997/98 southward migration (Angliss and Lodge 2004). Surveys conducted from December 2001 to March 2002 resulted in an abundance estimate of 17,414 (Rugh 2004). The lower encounter rate in 2001–2002 may be a result of fewer whales migrating as far south as Granite Canyon, where the

surveys took place, or an actual decline in abundance following high mortality in 1999 and 2000 (Rugh 2004). Gray whale numbers increased steadily until at least 1998, with an estimated annual growth rate of 3.29% between 1967 and 1988 (Buckland et al. 1993b). Recent reductions in abundance estimates may be a function of the population reaching its carrying capacity (Rugh 2004). The gray whale was removed from the endangered species list in 1994.

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale has a nearly cosmopolitan distribution, occurring in all ocean basins from the Bering Sea and northern Greenland to the pack-ice zone around Antarctica (Rice 1998). Although it is considered a mainly coastal species, it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). The worldwide population of humpback whales is divided into northern and southern ocean populations (Mackintosh 1965).

The population size of the North Pacific humpback whale stock is estimated at >6000 (Calambok-idis et al. 1997), but under the ESA provisions, it is officially considered an ***Endangered*** species. Within the U.S., there are at least three stocks: California/Oregon/Washington and Mexico; Central North Pacific; and Western North Pacific. Whales of the Central and Western North Pacific stocks occur in Alaskan waters. Whales of the Central North Pacific stock winter in Hawaii and migrate to SE Alaska, PWS, the GOA, and Kodiak Island to feed (Calambokidis et al. 1997). The Western North Pacific stock winters near Japan and likely migrates to the Bering Sea and Aleutian Islands in summer (Darling et al. 1996). However, little is known about feeding areas for the Western North Pacific stock, although some are known to occur in areas occupied by humpback whales of the Central North Pacific stock.

The Western North Pacific humpback whale stock is estimated at 394 and the Central North Pacific stock at 4005 (Calambokidis et al. 1997). Waite et al. (1999) identified 127 individuals near the Kodiak area from 1991 to 1994 and calculated a total abundance estimate of 651 for the Kodiak region. Waite et al. (1999) also sighted 22 humpback whales near Shumagin Islands, 8 to the southeast of Shumagin Islands, and 7 near Akutan Island. Only 7 of those animals have been documented in PWS or SE Alaska, which indicates that waters west of Kodiak Island support a discrete feeding aggregation, although it is not known where these whales overwinter (Waite et al. 1999). During July 2003, two killer whales were seen harassing a humpback whale mother and calf east of the Shumagin Islands (Wade et al. 2003).

Humpback whales are considered common in nearshore waters of the eastern Aleutian Islands. They were the second-most frequently-encountered cetacean and the most commonly-seen large whale during surveys on the south side of the Aleutian Islands in 1994 (Forney and Brownell 1996). Forney and Brownell (1996) made 57 sightings, mostly in deep, offshore waters over the Aleutian Trench or the Aleutian Abyssal Plain. During summer surveys from the Kenai Fjord to the central Aleutian Islands in 2001–2003, 407 sightings of 773 humpbacks were made; the mean group size was 1.9 (Wade et al. 2003). During the Splash 2004 Cruise from 12 to 25 August, nine humpback whales were seen in the Aleutian Islands (Barlow 2004a,b). Zerbini et al. (2003) noted that humpback whales are primarily seen from the Kenai Peninsula to Umnak Island. Waite (2003) reported that 117 humpbacks were seen in 41 groups during surveys in the northern GOA in 2003. Zerbini et al. (2004) estimated the abundance of humpback whales in the northern GOA and Aleutian Islands at 2866.

During recent surveys in the CEBS and SEBS, 11 sightings of 18 humpbacks were made, mainly southwest of St. Lawrence Island and outside of Bristol Bay (Moore et al. 2002b). Abundance in the CEBS has been estimated to range from 102 to 1175 (Moore et al. 2000, 2002b). Density in the SEBS was calculated at $0.00064/km^2$ (Moore et al. 2002b).

Humpback whales are often sighted singly or in groups of two or three, but while in their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983). Moore et al. (2002b) noted group sizes of 1.8 and 1.3 in the CEBS and SEBS, respectively. The results of diet studies conducted during commercial whaling operations identified a wide range of prey species for humpbacks in the North Pacific (Frost and Lowry 1981). Humpback whale feeding has been studied in great detail in Glacier Bay National Park and Preserve (GBNPP). Whales in GBNPP typically feed alone or in pairs, primarily on small schooling fishes such as capelin *Mallotus villosus*, juvenile walleye pollock *Theragra chalcogramma*, sand lance *Ammodytes hexapterus*, and Pacific herring *Clupea harengus pallasi* (Wing and Krieger 1983; Krieger and Wing 1984). Whales in GBNPP tend to feed below the surface. Lunge feeding, bubblenet feeding, and other surface feeding modes were commonly seen in the 1970s (Jurasz and Palmer 1979) but are now rarely seen (Baker 1985; Gabriele 1995).

Sexual maturity is reached at about 5 years (Clapham 2002). Females usually give birth to one calf every 2 years, although annual calving is also known to occur (Clapham and Mayo 1990; Glockner and Ferrari 1990). Gestation lasts ~11 months, and most calves are born during mid-winter at low latitudes (Clapham 2002).

Humpback males sing long, complex songs on their wintering grounds (Payne and McVay 1971). The songs are shared by all singing whales while on the breeding grounds. They may serve to attract reproductive females or may be a form of competitive behavior with other whales. Humpback songs have been recorded on feeding grounds in Stellwagen Bank in the North Atlantic (Mattila et al. 1987) and in SE Alaska (McSweeney et al. 1989). Songs appear to be rare in summer, but become more common in fall, and are heard in pelagic waters as whales migrate to wintering grounds (Mattila et al. 1987). The songs heard on the summering grounds are generally condensed versions of songs heard during the previous and subsequent winters. The function of songs on the summer feeding grounds is unknown.

Humpback whales have also been recorded uttering stylized rhythmic vocalizations identified as "feeding calls" (Jurasz and Jurasz 1979a) and "cries" while feeding cooperatively in SE Alaska (Cerchio and Dahlheim 2001). The cries may play a role in prey manipulation (Baker 1985), creating a broad band of frequencies to which their prey may be sensitive. Humpback whales produce sounds in the frequency range 20 Hz–8.2 kHz, although songs have dominant frequencies of 120–4000 Hz (review by Thomson and Richardson 1995).

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales are small baleen whales that inhabit all oceans of the world from high latitudes to near the equator (Leatherwood et al. 1982). In the Northern Hemisphere, minke whales usually are seen in coastal areas, but can be seen in pelagic waters during northward migrations in spring and summer, and southward migration in autumn (Stewart and Leatherwood 1985). Two minke whale stocks are recognized in U.S. waters, the Alaskan stock and the California/Oregon/Washington (COW) stock (Angliss and Lodge 2004).

Minke whales are relatively common in the Bering and Chukchi seas and in the inshore waters of the GOA (Mizroch 1992), and are considered common in the Aleutian Islands. However, they are not considered abundant in any other part of the eastern Pacific (Brueggeman et al. 1990). There are no population estimates for the Pacific population as a whole or for the Alaskan stock. Estimates of minke whales in the CEBS and SEBS were 810 and 1003 whales, respectively, based on 28 on-transect sightings in these areas (Moore et al. 2002b). Densities of minke whales in the CEBS and SEBS were calculated as 0.0041/km^2 and 0.0063/km^2, respectively (Moore et al. 2002b).

A total of 96 sightings of single minke whales were made during surveys in summer 2001–2003 extending from the Kenai Fjord to the central Aleutian Islands, and in 2001, three killer whales were observed attacking a minke whale near the Shumagin Islands (Wade et al. 2003). Moore (2001) noted the occurrence of resident minke whales in Akutan Pass. During the Splash 2004 Cruise from 12 to 25 August, five minke whales were seen in the Aleutian Islands (Barlow 2004a). Forney and Brownell (1996) also noted five sightings of minke whales during surveys around the Aleutian Islands. Zerbini et al. (2004) estimated the abundance of minke whales in the northern GOA and Aleutian Islands at 1512. Minke whales are taken incidentally during groundfish trawls in the Bering Sea and Aleutian Islands at an estimated annual mortality of 0.3 (Angliss and Lodge 2004).

Females attain sexual maturity at ~7 years and males are sexually mature at 6 years (Stewart and Leatherwood 1985). Females give birth every year with gestation lasting ~10 months and calving typically occurring from November to March (Sergeant 1963). Minke whales are relatively solitary, but may occur in aggregations of up to 100 when food resources are concentrated. The small size, incon-spicuous blows, and brief surfacing times of minke whales mean that they are easily overlooked in heavy sea states, although they are known to approach vessels in some circumstances (Stewart and Leatherwood 1985). Detection of minke whales with listening devices is unreliable. A large variety of sounds, ranging in frequency from 60 Hz to 12 kHz, has been attributed to minke whales (Stewart and Leatherwood 1985; Edds-Walton 2000; Mellinger et al. 2000; Gedamke et al. 2001).

Sei Whale (*Balaenoptera borealis*)

The sei whale has a nearly cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). In the eastern Pacific, sei whales range in the summer from the Bering Sea and the northern GOA to the coast of southern California, but they are considered uncommon in the Aleutian Islands (Sobolevsky and Mathisen 1996). Four sightings of six sei whales were made in 1999 and 2000, during surveys in the CEBS and SEBS, respectively (Moore et al. 2002b). Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The sei whale is listed as ***Endangered*** under the ESA.

In the open ocean, sei whales generally migrate from temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (Gambell 1985a). Winter sightings have been made between southern Baja California and the Islas Revilla Gigedo (Rice 1998). Sei whales are mainly pelagic, and usually occur in small groups of up to six individuals. They tend to make shallow dives and surface relatively frequently. They apparently produce sounds in the range 1.5–3.5 kHz, though few data on their calls are available (review by Thomson and Richardson 1995).

Fin Whale (*Balaenoptera physalus*)

Fin whales are widely distributed in all the world's oceans (Gambell 1985b), but typically occur in temperate and polar regions. They appear to have complex seasonal movements, and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, and migrate to northern latitudes during the summer to feed (Mackintosh 1965). The North Pacific population summers from the Chukchi Sea to California, and winters from California southwards (Gambell 1985b).

A total of 276 sightings of 580 fin whales were made during surveys from the Kenai Fjord to the central Aleutian Islands in the summers of 2001–2003 (Wade et al. 2003). The mean group size was 2.1 (Wade et al. 2003). Forney and Brownell (1996) reported four sightings of fin whales in slope and shelf waters around the Aleutian Islands. Fin whales were also seen near Semidi Island and Shumagin Islands during June 2001 (Moore 2001). During the Splash 2004 Cruise from 12 to 25 August, four fin whales

were seen in the Aleutian Islands (Barlow 2004b). Zerbini et al. (2003) noted that fin whales are primarily seen from the Kenai Peninsula to the Shumagin Islands. During surveys in the CEBS and SEBS, 88 sightings of 269 fin whales were made (Moore et al. 2002b). Fin whale density was higher in the CEBS (0.017/km^2) than in the SEBS (0.0043/km^2), and the abundance estimate for the CEBS (3368) was ~5x the estimate of 683 for the SEBS (Moore et al. 2002b). Zerbini et al. (2004) estimated the abundance of fin whales in the northern GOA and Aleutian Islands at 1484.

Fin whales are incidentally taken in the Bering Sea/Aleutian Islands groundfish trawl fishery at an estimated annual mortality of 0.6 (Angliss and Lodge 2004).

Recent information about the seasonal distribution of fin whales in the North Pacific has been obtained from the reception of fin whale calls by bottom-mounted, offshore hydrophone arrays along the U.S. Pacific coast, in the central North Pacific, and in the western Aleutian Islands (Moore et al. 1998; Watkins et al. 2000a,b). Near the Alaska Peninsula in the western GOA (Site 7; Moore et al. 1998) the number of calls received peaked in May–August, with few calls through the rest of the year. Calls were received relatively uniformly from July to September, with small peaks in November, February, and May at the northernmost site along the USWC (Site 5; Moore et al. 1998). The patterns of fin whale call reception generally corresponded to seasonal productivity in the areas monitored. Fin whale call rates peaked during fall and winter in the central North Pacific and the Aleutian Islands, but this species was also detected during summer (Moore et al. 1998; Watkins et al. 2000a,b).

Fin whales occur in coastal, shelf, and oceanic waters. Moore et al. (2002b) noted that in the CEBS and SEBS, sighting rates were more than twice as high in water >100 m deep than in water 50–100 m deep; no sightings occurred in water <50 m deep. Sergeant (1977) proposed that fin whales tend to follow steep slope contours, either because they detect them readily or because biological productivity is high along steep contours because of tidal mixing and perhaps current mixing. Fin whales are typically observed alone or in pairs, but on feeding grounds, up to 20 individuals can occur together. Moore et al. (2002b) noted average group sizes in the CEBS and SEBS of 3.2 and 1.8, respectively.

The diving behavior of fin whales in the western North Atlantic was reviewed by Stone et al. (1992) with the objective of evaluating the likelihood of detection by aerial and shipboard surveys. Fin whales in their study area blew about 50 times/h, and the average dive time was about 3 min. As fin whales usually do not remain submerged for long periods, have tall blows, have a conspicuous surfacing profile, and often occur in groups of several animals, they are less likely to be overlooked than most other species.

The distinctive 20-Hz pulses of fin whales, with source levels as high as 180 dB re 1 μPa, can be heard reliably to distances of several tens of kilometers (Watkins 1981; Watkins et al. 1987; Edds 1988; Cummings and Thompson 1994) or even further (Cummings and Thompson 1971; Payne and Webb 1971). Watkins (1981) believed that most fin whale responses to singers are at distances <15 km. Fin whales primarily emit their 20-Hz signals during their reproductive season, from autumn to early spring. Watkins et al. (1987) believed that the repetitive signals are an acoustic display associated with repro-duction, and Croll et al. (2002) reported that it is the males that make strong calls. Fin whales also produce sounds at frequencies up to 150 Hz, including 34–75 Hz tones, a 129–150 Hz tone preceding 20 Hz sounds, and generally downsweeping pulses in the range 118–14 Hz (Watkins 1981; Cummings et al. 1986; Edds 1988). Watkins (1981) heard those sounds mostly during interactions of two or more whales, and speculated that the sounds were used to communicate with nearby whales. Fin whales more than 15–20 km from one another apparently do not emit the higher-frequency sounds (Watkins 1981).

Probably at least in part because of their initially high abundance, wide distribution, and diverse feeding habits, fin whales apparently were not as badly depleted as the other large whales in the North

Pacific. However, the species is listed as ***Endangered*** under the ESA, and it is a CITES Appendix I species (Table 4).

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout most of the world's oceans, occurring in coastal, shelf, and oceanic waters. The worldwide population has been estimated at 15,000, with 10,000 in the Southern Hemisphere (Gambell 1976), 3500 in the North Pacific, and up to 1400 in the North Atlantic (NMFS 1998). Broad-scale acoustic monitoring indicates that blue whales of the Northeast Pacific stock may range from the Eastern Tropical Pacific along the coast of North America to Canada, and offshore at least 500 km (Stafford et al. 1999, 2001). Blue whales have been detected in the North Pacific by identifying stereotypic calls detected via offshore hydrophones (e.g., Stafford et al. 1998; Watkins et al. 2000a,b; Moore et al. 2002a). Blue whale calls monitored from the U.S. Navy Sound Surveillance System (SOSUS) and other offshore hydrophones suggest that separate populations occur in the eastern and western North Pacific (Stafford et al. 1999, 2001; Watkins et al. 2000a).

Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in winter, where they mate and give birth (Lockyer and Brown 1981). Little is known about the movements and wintering grounds of the stocks (Mizroch et al. 1984). Some individuals may stay in low or high latitudes throughout the year (Reilly and Thayer 1990; Watkins et al. 2000b). Moore et al. (2002a) reported that blue whale calls are received in the North Pacific year-round, indicating that this area is suitable habitat for blue whales year-round. However, the number of whales producing the calls remains unknown.

The distribution of blue whales, at least during times of the year when feeding is a major activity, is in areas that provide large seasonal concentrations of euphausiids, which are the blue whale's main prey (Yochem and Leatherwood 1985). One population feeds in the Northeast Pacific from June to November and migrates south in winter/spring (Calambokidis et al. 1990; Mate et al. 1999). Blue whale call locations from the Northwest Pacific were closely associated with cold water and sharp sea surface temperature gradients or fronts, probably corresponding to zooplankton concentrations (Moore et al. 2002a). Blue whale distribution in the Northwest Pacific appears to be associated with the Emperor Seamounts (south of the Aleutian Islands), the steep continental slope off the Kamchatka Peninsula, and the Aleutian Islands (Moore et al. 2002a). In the summer, concentrations of blue whale calls were evident in the waters between the seamounts and the Aleutian Islands, and in the spring, blue whale locations were associated with high chlorophyll *a* concentrations (Moore et al. 2002a).

Blue whales are considered rare in the Aleutian Islands. During the Splash 2004 Cruise from 12 to 25 August, two blue whales were seen in the Aleutian Islands. One was seen at the far western end of the Aleutian archipelago, and the other ~130 km south-southeast of Tanaga Island (Barlow 2004b). Farther east, three blue whales were seen in mid July 2004 at a location 200–250 km southeast of PWS at a water depth of ~3000 m, and 15 were seen from the R/V *Maurice Ewing* in August 2004 near Dixon Entrance.

Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999). Blue whales attain sexual maturity at 5–15 years of age (Sears 2002). The lengths at sexual maturity for blue whales in the Northern Hemisphere are 21–23 m for females and 20–21 m for males, (Yochem and Leatherwood 1985). Blue whales calve and mate in the late fall and winter (Yochem and Leatherwood 1985). Females give birth in the winter to a single calf every 2–3 years (Sears 2002). The gestation period is usually estimated to be 10–12 months (Sears 2002).

Blue whales have a tall and conspicuous blow, and may lift their flukes clear of the surface before a deep dive. Dives can last from 10–30 min and are usually separated by a series of 10–20 shallow dives. Swimming speed has been estimated at 2–6.5 km/h while feeding, and 5–33 km/h while traveling (Yochem and Leatherwood 1985). The best-known sounds of blue whales consist of low-frequency "moans" and "long pulses", which range from 12.5 to 200 Hz and can have source levels up to 188 dB re 1 µPa (Cummings and Thompson 1971).

All populations of blue whales have been exploited commercially, and many have been severely depleted as a result. The blue whale is listed as ***Endangered*** under the ESA and by IUCN, and is listed in CITES Appendix I (Table 4).

Pinnipeds

Steller Sea Lion (*Eumetopias jubatus*)

Steller sea lions occur in the coastal and immediate offshore waters of the North Pacific. In the western Pacific, they are distributed from the Bering Strait along the Aleutian Islands, the Kuril Islands, and the Okhotsk Sea to Hokkaido, Japan. In the eastern Pacific, they occur along the coast of North America south to the Channel Islands off Southern California (Rice 1998). Two stocks of Steller sea lions are recognized in Alaskan waters, based on differences in population dynamics (York et al. 1996) and mitochondrial DNA sequence distribution (Bickham et al. 1996). Cape Suckling (144º W longitude) forms the boundary between the two stocks, known as the Eastern and Western populations (Loughlin 1997). Aerial and ground-based surveys suggest that the minimum population size of the Eastern stock of Steller sea lions, including animals in British Columbia, Washington, Oregon, and California, is 31,028 (Angliss and Lodge 2004). The minimum population estimate for the Western stock is 34,779 (Angliss and Lodge 2004). Steller sea lions are present in Alaska year round, with centers of abundance in the GOA and Aleutian Islands.

Critical habitat for Steller sea lions has been identified in the Code of Federal Regulations (50 CFR 226.202). It includes 66 sites (26 rookeries and 40 haulouts) in the Aleutian Islands, and foraging areas in Seguam Pass and in the Bogoslof area. Shelikof Strait is another critical foraging area, but it is located on the south side of the Alaska Peninsula. Areas of critical habitat are more extensive for the Western stock than for the Eastern stock. Critical habitat includes land 3000 ft (914 m) inshore from the baseline or basepoint of each major rookery and major haulout in Alaska. It also includes waters 3000 ft (914 m) seaward in state- and federally-managed waters from every major rookery and haulout east of 144ºW, and 20 n.mi. (37 km) seaward from every major rookery and haulout west of 144ºW (50 CFR 226.202). In addition, "no approach" zones have been identified wherein no vessel may approach within 3 n.mi. (5.6 km) of listed rookeries. Many of these zones occur within the proposed study area.

The Steller sea lion was declared a ***Threatened*** species throughout its range in 1990, and the Western stock was listed as ***Endangered*** in 1997. The determinations were a result of the precipitous decline in the Alaskan population from 140,000 in 1956 to 60,000–68,000 in 1985 (Merrick et al. 1987). From Kenai Peninsula to Kiska Island, Loughlin et al. (1990) noted a decline of 63% from 1985 to1989. Worldwide, the population dropped from 240,000–300,000 to 116,000 (Loughlin et al. 1992) during a 30-year period. The decline in numbers has been greatest for the Western stock, with some breeding rookeries in the Aleutians declining as much as 87% from 1960 to 1989 (Loughlin et al. 1992). The causes of the decline in the Western stock are not known. Several hypotheses, including food stress, direct human interaction, indirect effects from human activities, natural climactic variation, and long-term shifts attributable to past human activities have been proposed (see summary in NRC 2003; Springer et al. 2003).

Surveys conducted in July 2002 showed the first region-wide increase in the Western stock since the 1970s (Sease and Gudmondson 2002). A total of 26,602 non-pups were counted in 2002, including 1199 sea lions in the western Aleutian Islands, 7035 in the central Aleutians, and 5358 in the eastern Aleutians. That was an increase of up to 6.8% at rookeries from counts in 2000. Nonetheless, the counts were still down from 1998 and down more than 30% since 1990 (Sease and Gudmondson 2002). From 1991 to 2002, the population declined up to 4.1% per year. A composite count of pups in 2001 and 2002 totaled 8345, an 11.2% decline since 1998. In the Aleutian Islands, the pup count was 4450.

In the central and western Aleutian Islands, Steller sea lion populations increased between 1959 and the 1970s, but numbers have declined since the late 1970s or early 1980s (Trites and Larkin 1996). The decline may have slowed in the 1990s (Trites and Larkin 1996). However, according to counts of Steller sea lions in the western Aleutian Islands, including Buldir and Near Islands, numbers there have continued to decline even since 2000 (Sease and Gudmondson 2002). The declines from 1998 to 2002 for pups and non-pups were 39 and 24%, respectively. The decline may actually extend as far east as Adak Island (Sease and Gudmondson 2002).

In the western Aleutian Islands, counts of sea lion pups and non-pups in 2001 and 2002 were highest at Agattu Island (Sease and Gudmondson 2002). In the central Aleutian Islands, the greatest number of sea lion pups occurred on Gramp Rocks, near Tanaga Island, and the highest count of non-pups was for Adak Island (Sease and Gudmondson 2002).

A decline in juvenile survival appears to be an important cause of the decline in the Western stock of Steller sea lions. Declines in the number of juvenile sea lions have been reported at many Alaskan rookeries and haulouts since the 1980s (Merrick et al. 1987; Loughlin et al. 1992). The ultimate causes of the decline in survivorship are not yet understood. The pregnancy rate of mature females in the GOA in April–May 1985 was 60%, which is slightly lower than the 67% pregnancy rate recorded there in 1975–1978 (NMFS 1992).

There has not been a concomitant decline in the Eastern stock; the number of Steller sea lions in SE Alaska increased as much as 70% from 1960 to 1989 (Loughlin et al. 1992). The Eastern stock is still listed as threatened (Angliss and Lodge 2004) although Kruse et al. (2001) report that abundance of the Eastern stock may be the highest ever recorded, and that re-evaluation of the threatened listing is warranted.

Breeding adults occupy rookeries from late May to early July (NMFS 1992). Males become sexually mature at 3–7 years and physically mature around 10 years. Physically-mature males may gain and hold a territory for up to 7 years (NMFS 1992). Females become sexually mature at 3–6 years and may produce young into their early 20s. Most females breed annually. Females frequently return to the same pupping site within the rookery in successive years.

Steller sea lions haul out on beaches and rocky shorelines of remote islands, often in areas exposed to wind and waves (NMFS 1992; Fig. 3). Haulouts are areas typically used by sea lions at times other than the breeding season, although some haulouts are used as rookeries. Rookeries generally are found on gently sloping beaches that are protected from waves (NMFS 1992; Fig. 3). Males arrive at rookeries in May to establish their territory and are soon followed by females, who pup within days of their arrival. Non-breeding males use haulouts or occupy sites at the periphery of rookeries during breeding season (NRC 2003). Pupping occurs from mid-May to mid-July (Pitcher and Calkins 1981) and peaks in June (Pitcher et al. 2002). Breeding typically occurs within 11–14 days postpartum (NMFS 1992). Steller sea lions spend more time at sea in the winter than during the breeding season (Sease and York 2003). Territorial males fast and remain on land during the breeding season (NMFS 1992). Andrews et al. (2001) estimated that females foraged for generally brief trips (7.1–25.6 hr) around rookeries, spending 49–76% of their time at the rookeries. Females with pups feed principally at night during the breeding season, and generally stay within 30 km of the rookeries in shallow (30–120 m) water (NMFS 1992).

Steller sea lion pups enter the water 2–4 weeks after birth (Sandegren 1970 *in* Raum-Suryan et al. 2002), but don't tend to move from their natal rookeries to haulouts with their mothers until they are 2–3 months (Merrick et al. 1988 *in* Raum-Suryan et al. 2002).

During the non-breeding season, sea lions may disperse great distances from the rookeries. Some juvenile sea lions from the Western stock have been observed at South Marble Island and Graves Rocks in GBNPP (Raum-Suryan 2001).

Steller sea lions are an important subsistence resource for Alaska Natives from SE Alaska to the Aleutian Islands. The Aleutian Island communities of Akutan, Atka, Nikolski, and Unalaska participate in the Steller sea lion subsistence harvest. In 2002, the Aleutian Islands total (estimated and expanded) subsistence take of ~105 Steller sea lions comprised 56.9% of the total Alaskan subsistence take (ADFG 2003). Akutan took ~3 sea lions in 2002, the lowest recorded catch in the decade; the highest (30) was in 1992. Atka reported the greatest annual catch of ~86 sea lions in 2002; the lowest had been in 1997 when ~12 animals were harvested. Nikolski reported a harvest of one sea lion in 2002; the highest take was reported to be ~8 animals in 1992. Unalaska harvested ~16 sea lions in 2002; ~69 sea lions were taken by the community of Unalaska in 1993, the highest recorded take from 1992 to 2002. In general, seasonal takes of sea lions by Alaska natives is lowest June through August (ADFG 2003). Of the four Aleutian Islands communities, only Akutan harvested a Steller sea lion in June 2002. None of the other communities reported harvests in June 2002 and none of the four reported July 2002 harvests (ADFG 2003). Steller sea lions of the Western stock also have been taken incidentally during commercial fishery operations, at a minimum annual mortality ≥31.3 (Angliss and Lodge 2004).

California Sea Lion (*Zalophus californianus*)

The California sea lion generally is found from southern Mexico to southwestern Canada. However, California sea lions have been sighted occasionally as far north as Alaska. They have been observed on Chiswell Island, PWS, and other parts of SE Alaska. Approximately 33 sightings have been recorded in Alaska, including some as far west as the Pribilof Islands (ASJ 2002).

The breeding areas of the California sea lion are on islands located in southern California, western Baja California, and the Gulf of California. Three stocks are recognized: (1) the U.S. stock, beginning at the U.S./Mexico border and extending north to Canada; (2) the Western Baja California stock, extending from the U.S/Mexican border to the southern tip of Baja California; and (3) the Gulf of California stock, in the Gulf of California from the southern tip of the peninsula and along the mainland coast, extending to southern Mexico (Lowry et al. 1992). The proposed survey area is outside of the California sea lion's normal range, and any California sea lions that might be seen would be considered extralimital.

The California sea lion population is growing at an annual rate of 5–6.2%. Recent population estimates range from 204,000 to 214,000 (Boveng 1988; Lowry et al. 1992; Lowry 1999). Sea lions are killed incidentally in set and drift-gillnet fisheries (Hanan et al. 1993; Barlow et al. 1994; Julian 1997; Julian and Beeson 1998; Cameron and Forney 1999). California sea lions are not listed as endangered or threatened under the ESA or as "depleted" under the MMPA.

Northern Fur Seal (*Callorhinus ursinus*)

Northern fur seals are endemic to the North Pacific Ocean, and they occur from southern California to the Bering Sea, the Okhotsk Sea, and Honshu Island, Japan. Two stocks are recognized in U.S. waters, the Eastern Pacific and the San Miguel Island stocks. The Eastern Pacific stock ranges from the Pribilof Islands and Bogoslof Island in the Bering Sea during summer to the Channel Islands in Southern California during winter.
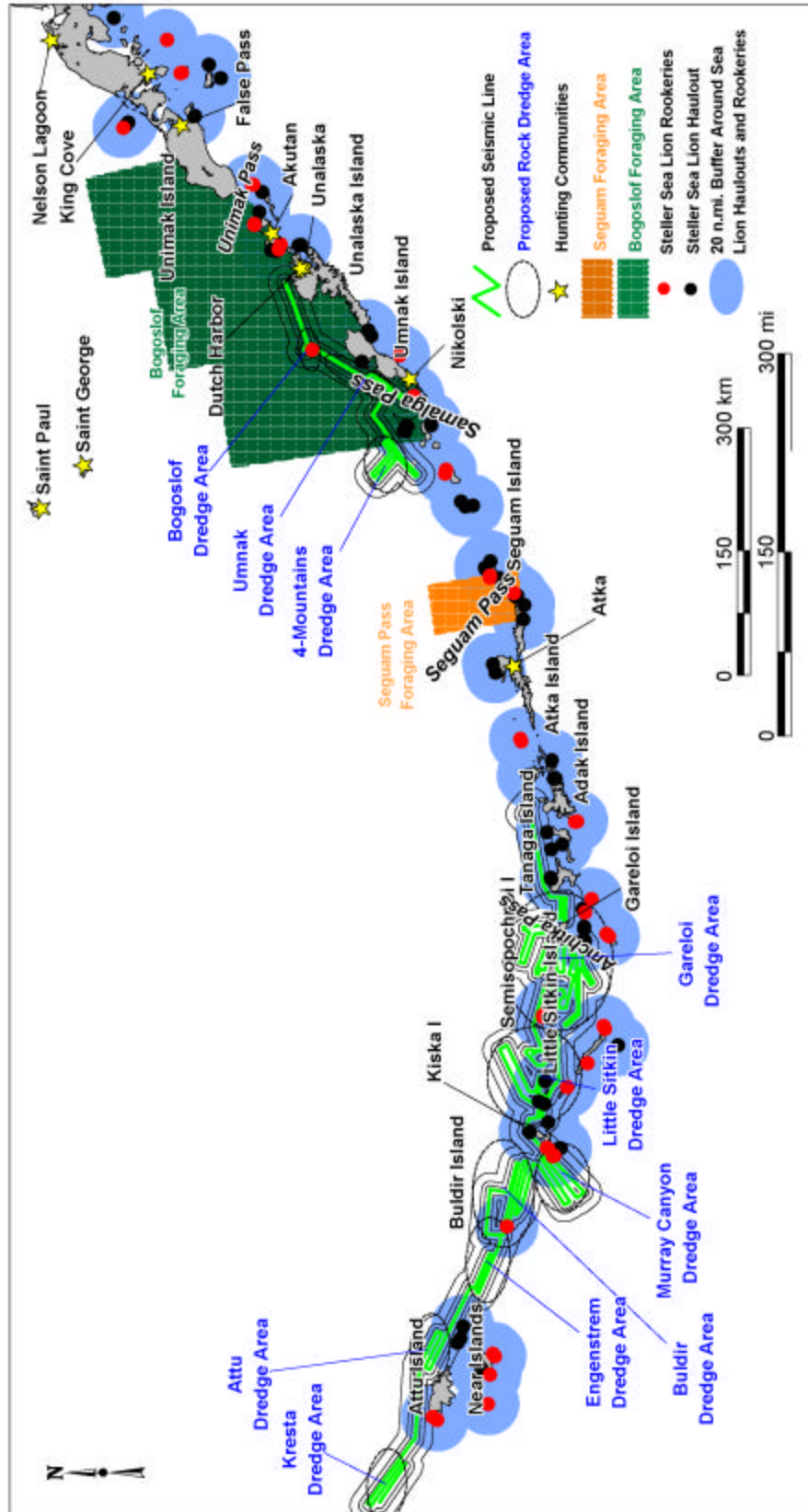
FIGURE 3. Steller sea lion rookeries and haulouts (all rookeries and major haulouts have 20 n. mi. critical habitat associated with them), and Steller sea lion and harbor seal harvesting communities near the planned seismic and scientific rock dredging program along the Aleutian Islands, Alaska.

During the breeding season (June–September), most of the world's population of northern fur seals occurs on the Pribilof and Bogoslof islands. Although the Pribilof Islands have always had the greatest number of fur seals, numbers are now declining there and increasing on Bogoslof Island (NMFS 2004b). Before the 1970s, few northern fur seals inhabited Bogoslof Island, but by 1980, they were more common there. From 1980 to 1997, the fur seal population on Bogoslof Island increased by 59% per year (NMFS 2004b).

When not on rookery islands, northern fur seals are primarily pelagic, but occasionally haul out on rocky shorelines. Adult females may migrate as far south as the Hawaiian Islands (NMML unpubl. data), but males are thought to remain in the North Pacific. Pups travel through Aleutian passes and spend the first two years at sea before returning to their islands of origin. A total of 42 northern fur seals were seen during 3767 km of shipboard surveys in the northwestern GOA during June–July 1987 (Brueggeman et al. 1988). Leatherwood et al. (1983) noted 14 sightings of 34 northern fur seals away from the breeding islands in the SE Bering Sea during aerial surveys in 1982, mostly during July and August.

The worldwide population of fur seals has declined from a peak of ~2.1 million in the 1950s to the current minimum population estimate of ~888,120 (Angliss and Lodge 2004). They were subjected to large-scale harvests on the Pribilof Islands to supply a lucrative fur trade, beginning with the discovery of the Pribilof Islands by Russian sealers in 1786. Prior to the 1940s, a few northern fur seals were also harvested by Alaska Native hunters in the Sitka area, presumably as they passed during their spring migration to the Pribilof Islands. By 1974, the population was 1.25 million (Angliss and Lodge 2004). From 1974 into the 1980s, the population decreased (York 1987), then was relatively stable from 1981 to 1995 (York and Fowler 1992). Pup production remained relatively stable in the early and mid 1990s (York et al. 1997), then declined in the late 1990s and into 2000 (Angliss and Lodge 2004).

Currently, northern fur seals are mainly harvested by Aleuts living on the Pribilof Islands. Northern fur seals are also incidentally taken in commercial fishery operations, with a minimum annual mortality ≥16.0 (Angliss and Lodge 2004).

Pacific Walrus (*Odobenus rosmarus divergens*)

Walruses occur in moving pack ice over shallow waters of the circumpolar Arctic coast (King 1983). There are two subspecies, the Atlantic walrus (*O. r. rosmarus*) and the Pacific walrus (*O. r. divergens*). The Pacific walrus ranges from the Bering Sea to the Chukchi Sea, occasionally moving to the East Siberian and Beaufort seas. Walruses are migratory, moving south with the advancing ice in autumn and north as the ice recedes in spring (Fay 1981). In the summer, most of the population of the Pacific walrus moves to the Chukchi Sea, but several thousands aggregate in the Gulf of Anadyr and in Bristol Bay (Angliss and Lodge 2004). During the late winter breeding season, walrus concentrations occur from the Gulf of Anadyr to southwest of St. Lawrence Island, and in the SEBS, from south of Nunivak Island to northwestern Bristol Bay (see Angliss and Lodge 2004). Although walruses may occur in the eastern Aleutians, they are rarely seen in the western Aleutians, and unlikely to be seen in the proposed study area, especially in the summer. Walruses are hunted outside of the Aleutian Islands, and the mean annual mortality of walruses from the Bering Sea groundfish trawl fishery is estimated at 1.2 (Angliss and Lodge 2004).

Harbor Seal (*Phoca vitulina richardsi*)

Harbor seals range from Baja California, north along the west coasts of the United States, British Columbia, and SE Alaska, west through the GOA, PWS, and the Aleutian Islands, and north in the Bering Sea to Cape Newenham and the Pribilof Islands. Angliss and Lodge (2004) identified three stocks in

Alaska: Southeast Alaska, GOA (including the Aleutian Islands), and Bering Sea. Angliss and Lodge (2004) estimated that there were 28,917 individuals in the Gulf of Alaska stock. Troy and Johnson (1989) noted a population estimate of 3459 harbor seals within the North Aleutian Shelf. Small et al. (2003) reported that harbor seal numbers increased significantly in the Ketchikan and Kodiak areas from 1983 to 2001, but were stable (no significant trends) in Sitka and Bristol Bay. In some parts of Alaska, harbor seal abundance has declined (Pitcher 1990; Frost et al. 1999). In PWS, numbers decreased by 57% from 1984 to 1992 (Pitcher 1989; Frost and Lowry 1993) and the decline continued (Frost et al. 1997). Numbers in the Kodiak Archipelago also decreased from the mid 1970s to the 1990s (Angliss and Lodge 2004). Residents of the Aleutian Island communities of Akutan, Atka, Nikolski, and Unalaska hunt harbor seals. Of the total Alaska harbor seal take in 2002 (1007 animals), the Aleutian Island communities harvested 65.9 (expanded count; ADFG 2003). Akutan, Atka, Nikolski, and Unalaska harvested 10.2, 36, 4, and 15.7 animals (expanded counts) respectively. The percent of total 2002 harbor seal takes for Akutan, Atka, Nikolski, and Unalaska harvested in June and July were 43%, 0%, 0%, and 18% respectively (ADFG 2003). Harbor seals are also taken incidentally during commercial fishery operations at an estimated annual mortality ≥35 (Angliss and Lodge 2004).

Harbor seals inhabit estuarine and coastal waters, hauling out on rocks, reefs, beaches, and glacial ice flows. They are generally non-migratory, but move locally with the tides, weather, season, food availability, and stage in their reproductive cycle (Scheffer and Slipp 1944; Fisher 1952; Bigg 1969, 1981). Juvenile harbor seals can travel significant distances (525 km) to forage or disperse, whereas adults generally were found within 190 km of the tagging location (Lowry et al. 2001) in PWS. The smaller home range used by adults is suggestive of strong site fidelity (Pitcher and Calkins 1979; Pitcher and McAllister 1981; Lowry et al. 2001). Female harbor seals give birth to a single pup while hauled out on shore or on glacial ice flows. In Alaska, pups are generally born in mid-June. The mother and pup remain together until weaning occurs at 3–6 weeks (Bishop 1967; Bigg 1969). Little is known about breeding behavior in harbor seals. When molting, which occurs primarily in late August, seals spend the majority of the time hauled out on shore, glacial ice, or other substrates.

Spotted Seal (*Phoca largha*)

Spotted seals occur in the Beaufort, Chukchi, Bering and Okhotsk seas, and south to the northern Yellow Sea and western Sea of Japan (Shaughnessy and Fay 1977). They migrate south from the Chukchi Sea and through the Bering Sea in October (Lowry et al. 1998). Spotted seals overwinter in the Bering Sea and inhabit the southern margin of the ice during spring (Shaughnessy and Fay 1977). In the summer and fall, spotted seals are known to occur around the Pribilof Islands, Bristol Bay, and the eastern Aleutian Islands (Angliss and Lodge 2004). Satellite telemetry evidence suggests that they may range much more widely in summer than suspected from conventional observations (Lowry et al. 1998, 2000). Spotted seals are occasionally hunted and are incidentally taken during commercial fisheries operations. The minimum annual mortality of spotted seals from commercial fisheries is ≥2.5 (Angliss and Lodge 2004).

Ringed Seal (*Pusa hispida*)

Ringed seals have a circumpolar distribution, and occur in all seas of the Arctic Ocean (King 1983). They are closely associated with ice, and in the summer, they often occur along the receding ice edges or farther north in the pack ice. In the North Pacific, they occur in the southern Bering Sea and range south to the seas of Okhotsk and Japan. They are found throughout the Beaufort, Chukchi, and Bering seas, and may occur as far south as Bristol Bay (Angliss and Lodge 2004). They are occasionally hunted in the Aleutian Islands, and have also been taken incidentally in the commercial groundfish fishery

(Angliss and Lodge 2004). Although they have been known to occur in the eastern Aleutians, that area is on the periphery of their range, and they likely will not be sighted in the study area.

Ribbon Seal (*Histriophoca fasciata*)

Ribbon seals occur in the North Pacific and adjacent Arctic Ocean. In Alaska, ribbon seals generally are found in the open sea and on pack ice (Kelly 1988c). They range from Bristol Bay into the Chukchi and western Beaufort seas. Ribbon seals inhabit the Bering Sea ice front from late March to early May and are abundant in the northern parts of the ice front in the central and western parts of the Bering Sea (Burns 1970; Burns 1981b). In May to mid July, when the ice recedes, some of the seals move farther north (Burns 1970; Burns. 1981c) to the Chukchi Sea (Kelly 1988c). However, most likely remain in the Bering Sea during the open-water season, and some occur on the Pacific Ocean side of the Aleutian Islands (Burns 1994). Ribbon seals are occasionally hunted in the Aleutians, and are also taken incidentally during the groundfish commercial fishery in the Bering Sea and Aleutian Islands with an estimated annual mortality of 0.2 (Angliss and Lodge 2004). Leatherwood et al. (1983) noted a ribbon seal just north of Unalaska Island during aerial surveys in 1982. This species is expected to be rare in the study area.

Bearded Seal (*Erignathus barbatus*)

Bearded seals are associated with sea ice and have a circumpolar distribution (Burns 1981a). During the open-water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981a). In Alaskan waters, bearded seals occur over the continental shelves of the Bering, Chukchi, and Beaufort Seas (Burns 1981a), and may occur as far south as the eastern Aleutian islands. Many bearded seals that winter in the Bering Sea migrate north to the Chukchi Sea for the summer, but some remain in the open-water areas of the Bering and Chukchi seas (Burns 1981a). Even though bearded seals may occur in the eastern Aleutians, they are unlikely to be seen in the study area in summer. They are hunted outside of the Aleutian Islands, and the mean annual mortality of bearded seals from the commercial fishery is 0.6 (Angliss and Lodge 2004).

Northern Elephant Seal (*Mirounga angustirostris*)

Northern elephant seals breed in California and Baja California, primarily on offshore islands (Stewart et al. 1994), from December to March (Stewart and Huber 1993). Juvenile elephant seals typically leave the rookeries in April or May and head north, traveling an average of 900–1000 km. However, most elephant seals return to their natal rookeries when they start breeding (Huber et al. 1991). When not at their breeding rookeries, elephant seals feed at sea far from the rookeries. Males may feed as far north as the eastern Aleutian Islands and the GOA; females feed farther south, south of 45ºN (Le Boeuf et al. 1993; Stewart and Huber 1993). They have been taken incidentally in groundfish commercial fisheries in the GOA, Bering Sea, and Aleutian Island (Angliss and Lodge 2004). They are considered to be rare in the Aleutian Islands (AMNWR 2004).

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED

> The type of incidental taking authorization that is being requested (i.e., takes by harassment only, takes by harassment, injury and/or death), and the method of incidental taking.

L-DEO requests an IHA pursuant to Section 101(a)(5)(D) of the MMPA for incidental take by harassment during its planned seismic survey in around the Aleutian Islands in June–July 2005.

The operations outlined in § I and II have the potential to take marine mammals by harassment. Sounds will be generated by the airguns used during the survey, by a multi-beam sonar, a hydrographic echo sounder, a 38-kHz ADCP, an acoustic positioning system, a pinger, and by general vessel operations. "Takes" by harassment will potentially result when marine mammals near the activities are exposed to the pulsed sounds generated by the airguns or sonars. The effects will depend on the species of cetacean or pinniped, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see § VII). Disturbance reactions are likely amongst some of the marine mammals in the general vic inity of the tracklines of the source vessel. No take by serious injury is antic ipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, "Mitigation Measures"). No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN

By age, sex, and reproductive condition (if possible), the number of marine mammals (by species) that may be taken by each type of taking identified in [section V], and the number of times such takings by each type of taking are likely to occur.

The material for Sections VI and VII has been combined and presented in reverse order to min-imize duplication between sections.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

The anticipated impact of the activity upon the species or stock of marine mammal.

The material for Sections VI and VII has been combined and presented in reverse order to min-imize duplication between sections.

- First we summarize the potential impacts on marine mammals of airgun operations, as called for in Section VII. A more comprehensive review of the relevant background information appears in Appendix A. That Appendix is little changed from corresponding parts of § VII in related IHA Applications previously submitted to NMFS concerning L-DEO projects in the following areas: northern Gulf of Mexico (2003 and planned 2004 projects), Hess Deep in the Eastern Tropical Pacific, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, southern Gulf of Mexico (Yucatan Peninsula), Oregon, southeast Alaska, and off the west coast of Central America.
- Then we discuss the potential impacts of operations by L-DEO's bathymetric sonar and pinger.
- Finally, we estimate the numbers of marine mammals that might be affected by the proposed activity in the Aleutian Islands during June–July 2005. This section includes a description of the rationale for L-DEO's estimates of the potential numbers of harassment "takes" during the planned survey, as called for in Section VI.

(a) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and (at least in theory) temporary or permanent hearing impair-ment or non-auditory physical effects (Richardson et al. 1995). Given the small size of the airgun source planned for the present project, its effects are anticipated to be considerably less than would be the case with a large array of airguns. It is very unlikely that there would be any cases of temporary or especially

permanent hearing impair ment, or non-auditory physical effects. Also, behavioral disturbance is expected to be limited to distances less than 275 m in deep (>1000 m) water and 750 m in shallow (<100 m) water.

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. For a summary of the characteristics of airgun pulses, see Appendix A (c). However, it should be noted that most of the measurements of airgun sounds that have been reported concerned sounds from larger arrays of airguns, whose sounds would be detectable considerably farther away than those planned for use in the present project.

Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix A (e). That is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. In general, pinnipeds and small odontocetes seem to be more tolerant of exposure to airgun pulses than are baleen whales. Given the small and low-energy GI gun source planned for use in this project, mammals are expected to tolerate being closer to the source than would be the case for a larger airgun source typical of most seismic surveys.

Masking

Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data of relevance. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a more recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Given the small source planned for use here, there is even less potential for masking of baleen or sperm whale calls during the present study than in most seismic surveys. Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses and the relatively low source level of the GI gun to be used here. Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Masking effects, in general, are discussed further in Appendix A (d).

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Based on NMFS (2001, p. 9293), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely

to be significant to the individual, let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are affected in some biologically-important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, small toothed whales, and sea otters. Most of those studies have concerned reactions to much larger airgun sources than the GI gun planned for use in the present project. Thus, effects are expected to be limited to considerably smaller distances and shorter periods of exposure in the present project than in most of the previous work concerning marine mammal reactions to airguns.

Baleen Whales.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, as reviewed in Appendix A(e), baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the case of the migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 µPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix A (e) have shown that some species of baleen whales, notably bowhead and humpback whales, at times show strong avoidance at received levels lower than 160–170 dB re 1µPa rms. Reaction distances would be considerably smaller during the present project, as only one small GI gun will be used.

Humpback whales summering in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 µPa on an approximate rms basis. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa (~rms). More detailed information on responses of humpback whales to seismic pulses during studies in Australia can be found in Appendix A (a).

Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173

dB re 1μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration and much ship traffic in that area for decades (Appendix A *in* Malme et al. 1984). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987). Populations of both gray whales and bowhead whales grew substantially during this time. In any event, the brief exposures to sound pulses from the proposed small GI-gun source are highly unlikely to result in prolonged effects.

Toothed Whales.—Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above and in Appendix A have been reported for toothed whales. However, systematic work on sperm whales is underway (Tyack et al. 2003).

Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of seismic vessels operating large airgun systems. However, some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when large arrays of airguns are firing. Nonetheless, there have been indications that small toothed whales sometimes move away, or maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Goold 1996; Calambokidis and Osmek 1998; Stone 2003). Similarly, captive bottlenose dolphins and beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). However, the animals tolerated high received levels of sound (pk–pk level >200 dB re 1 μPa) before exhibiting aversive behaviors. With the presently-planned small GI gun, such levels would only be found within a few meters of the gun.

There are no specific data on the behavioral reactions of beaked whales to seismic surveys. A few beaked whale sightings have been reported from seismic vessels (Stone 2003). However, most beaked whales tend to avoid approaching vessels even without the added noise from airguns (e.g., Kasuya 1986; Würsig et al. 1998). There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operations, are ongoing nearby—see Appendix A(g). The strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown (see "Strandings and Mortality", below). Given the equivocal (at most) evidence of beaked whale strandings in response to operations with large arrays of airguns, strandings in response to a single GI gun are very unlikely.

Sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds, and it is to be expected that they would tend to avoid an operating seismic survey vessel. There were some limited early observations suggesting that sperm whales in the Southern Ocean and Gulf of Mexico might be fairly sensitive to airgun sounds from distant seismic surveys. However, more extensive data from recent studies in the North Atlantic suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (McCall Howard 1999;

Madsen et al. 2002; Stone 2003). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico has been done recently (Tyack et al., *in* Jochens and Biggs 2003).

Odontocete reactions to large arrays of airguns are variable and, at least for small odontocetes, seem to be confined to a smaller radius than has been observed for mysticetes. Thus, behavioral reactions of odontocetes to the small GI gun to be used here are expected to be very localized.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to the small gun source that will be used. Visual monitoring from seismic vessels, usually employing much larger sources, has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix A(e). Those studies show that pinnipeds frequently do not avoid the area within a few hundred meters of operating airgun arrays, even for arrays much larger than the one GI gun to be used here (e.g., Harris et al. 2001). However, initial telemetry work suggests that avoidance and other behavioral reactions to small airgun sources may at times be stronger than evident to date from visual studies of pinniped reactions to airguns (Thompson et al. 1998). Even if reactions of the species occurring in the present study area are as strong as those evident in the telemetry study, reactions are expected to be confined to relatively small distances and durations, with no long-term effects on pinniped individuals or populations.

Additional details on the behavioral reactions (or the lack thereof) by all types of marine mammals to seismic vessels can be found in Appendix A.

Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this for marine mammals exposed to sequences of airgun pulses. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 µPa (rms), respectively (NMFS 2000). Those criteria have been used in defining the safety (=shut-down) radii planned for the proposed seismic survey. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause temporary auditory impairment in marine mammals. As discussed in Appendix A (f) and summarized here,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary threshold shift (TTS), let alone permanent auditory injury, at least for delphinids.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

NMFS is presently developing new noise exposure criteria for marine mammals that take account of the now-available data on TTS in marine (and terrestrial) mammals.

Because of the small size of the gun source in this project (a single 105 in^3 GI gun), along with the planned monitoring and mitigation measures, there is little likelihood that any marine mammals or sea turtles will be exposed to sounds sufficiently strong to cause even the mildest (and reversible) form of hearing impairment. Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the single GI gun (and multi-beam bathymetric sonar), and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment (see § II(3), MITIGATION MEASURES). In addition, many cetaceans are likely to show some avoidance of the

area with high received levels of airgun sound (see above). In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid any possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that theoretically might occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. It is especially unlikely that any effects of these types would occur during the present project given the small size of the source, the brief duration of exposure of any given mammal, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, permanent threshold shift (PTS), and non-auditory physical effects.

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002). Given the available data, the received level of a single seismic pulse might need to be ~210 dB re 1 μPa rms (~221–226 dB pk–pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel operating a large array of airguns. Such levels would be limited to distances within a few meters of the small GI-gun source to be used in this project.

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. However, no cases of TTS are expected given the small size of the source, and the strong likelihood that baleen whales would avoid the approaching GI gun (or vessel) before being exposed to levels high enough for there to be any possibility of TTS.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999; Ketten et al. 2001; *cf*. Au et al. 2000). However, more recent indications are that TTS onset in the most sensitive pinniped species studied (harbor seal) may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2004).

A marine mammal within a radius of ≤100 m around a typical large array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel. (As noted above, most cetacean species tend to avoid operating airguns, although not all

individuals do so.) However, several of the considerations that are relevant in assessing the impact of typical seismic surveys with arrays of airguns are not directly applicable here:

- The planned GI gun source is much smaller, with correspondingly smaller radii within which received sound levels could exceed any particular level of concern (Table 1).

- "Ramping up" (soft start) is standard operational protocol during startup of large airgun arrays in many jurisdictions. Ramping up involves starting the airguns in sequence, usually commencing with a single gun and gradually adding additional guns. This is impractical for the single GI-gun source planned for use in the present project.

- With a large airgun array, it is unlikely that cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. In this project, the gun source is much less strong, so the radius of influence and duration of exposure to strong pulses is much smaller, especially in deep and intermediate-depth water.

- With a large array of airguns, TTS would be most likely in any odontocetes that bow-ride or otherwise linger near the airguns. In the present project, the anticipated 180 dB distances in deep and intermediate-depth water are 54 and 81 m, respectively (Table 1), and the waterline at the bow of the *Kilo Moana* will be ~97 m ahead of the GI gun.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 µPa (rms). The 180 and 190 dB distances for the GI gun operated by L-DEO vary with water depth. They are estimated to be no more than 27 m and 10 m, respectively, in deep water, but are predicted to increase to 200 m and 125 m, respectively, in shallow water (Table 1). Furthermore, those sound levels are ***not*** considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, TTS data that are now available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses much stronger than 180 dB re 1 µPa rms.

Permanent Threshold Shift (PTS).—When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level 20 dB or more above that inducing mild TTS if the animal were exposed to the strong sound for an extended period or to a strong sound with very rapid rise time—see Appendix A (f).

It is highly unlikely that marine mammals could receive sounds strong enough (and over a sufficient duration) to cause permanent hearing impairment during a project employing a single GI gun. In the proposed project, marine mammals are unlikely to be exposed to received levels of seismic pulses strong enough to

cause TTS, as they would probably need to be within a few meters of the GI gun for that to occur. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the GI gun may not be sufficient to induce PTS, especially because a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside the gun for a period longer than the inter-pulse interval. Baleen whales generally avoid the immediate area around operating seismic vessels. The planned monitoring and mitigation measures, including visual monitoring and shut downs of the GI gun when mammals are seen within the "safety radii", will minimize the already-minimal probability of exposure of marine mammals to sounds strong enough to induce PTS.

Non-auditory Physiological Effects.—Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of those effects occur in marine mammals exposed to sound from airgun arrays (even large ones). However, there have been no direct studies of the potential for airgun pulses to elicit any of those effects. If any such effects do occur, they probably would be limited to unusual situations when animals might be exposed at close range for unusually long periods.

It is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. That is especially so in the case of the proposed project where the GI gun is small, the ship is moving at 9 knots, and for the most part each survey does not encompass a large area.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at that frequency, the ensuing resonance could cause damage to the animal. A recent workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise pulses from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused the stranding. Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. However, a short paper concerning beaked whales stranded in the Canary Islands in 2002 suggests that cetaceans might be subject to decompression injury in some situations (Jepson et al. 2003). If so, that might occur if they ascend unusually quickly when exposed to aversive sounds. However, the interpretation that the effect was related to decompression injury is unproven (Piantadosi and Thalmann 2004; Fernández et al. 2004). Even if that effect can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds. It is especially unlikely in the case of the proposed survey, involving only one GI gun.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances and probably to projects involving large arrays of airguns. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are especially unlikely to incur auditory impairment or other physical effects. Also, the planned monitoring and mitigation measures include shut downs of the GI gun, which will reduce any such effects that might otherwise occur.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey, has raised the possibility that beaked whales exposed to strong pulsed sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding. Appendix A (g) provides additional details.

Seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to physical damage and mortality (NOAA and USN 2001; Jepson et al. 2003), even if only indirectly, suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

In May 1996, 12 Cuvier's beaked whales stranded along the coasts of Kyparissiakos Gulf in the Mediterranean Sea. That stranding was subsequently linked to the use of low- and medium-frequency active sonar by a North Atlantic Treaty Organization (NATO) research vessel in the region (Frantzis 1998). In March 2000, a population of Cuvier's beaked whales being studied in the Bahamas disappeared after a U.S. Navy task force using mid-frequency tactical sonars passed through the area; some beaked whales stranded (Balcomb and Claridge 2001; NOAA and USN 2001).

In September 2002, a total of 14 beaked whales of various species stranded coincident with naval exercises in the Canary Islands (Martel n.d.; Jepson et al. 2003; Fernández et al. 2003). Also in Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel *Maurice Ewing* was operating a 20-gun, 8490-in^3 array in the general area. The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). Nonetheless, that plus the incidents involving beaked whale strandings near naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

The present project will involve a much smaller sound source than used in typical seismic surveys. That, along with the monitoring and mitigation measures that are planned, and the infrequent occurrence of beaked whales in the project area, will minimize any possibility for strandings and mortality.

(b) Possible Effects of Bathymetric Sonar Signals

A multi-beam bathymetric sonar (Atlas Hydrosweep DS-2, 15.5-kHz) will be operated from the source vessel during the planned survey in the ETP. Details about this equipment were provided in § I. Sounds from the multi-beam sonar are very short pulses, occurring for 1–10 ms once every 1 to 15 s, depending on water depth. Most of the energy in the sound pulses emitted by this multi-beam sonar is at high frequencies, centered at 15.5 kHz. The beam is narrow (2.67º) in fore–aft extent, and wide (140º) in the cross-track extent. Each ping consists of five successive transmissions (segments) at different cross-track angles. Any given mammal at depth near the track line would be in the main beam for only one or two of the five segments, i.e. for 1/5th or at most 2/5th of the 1–10 ms.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Atlas Hydrosweep, (2) have a longer pulse duration, and (3) are directed close

to horizontally, vs. downward for the Hydrosweep. The area of possible influence of the Hydrosweep is much smaller—a narrow band below the source vessel. Marine mammals that encounter the Hydrosweep at close range are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses.

Masking

Marine mammal communications will not be masked appreciably by the multi-beam sonar signals given the low duty cycle of the sonar and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. However, all of these observations are of limited relevance to the present situation. Pulse durations from these sonars were much longer than those of the L-DEO multi-beam sonar, and a given mammal would have received many pulses from the naval sonars. During L-DEO's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

Captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1 s pulsed sounds at frequencies similar to those that will be emitted by the multi-beam sonar used by L-DEO, and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002). The relevance of these data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in either duration or bandwidth as compared with those from a bathymetric sonar.

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to those of the *Ewing*'s multi-beam sonar. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the bathymetric sonar sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals. Also, in the present project, it is very unlikely that any pinnipeds will be encountered.

As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from the multi-beam bathymetric sonar system would not result in a "take" by harassment.

Hearing Impairment and Other Physical Effects

Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the multi-beam sonar proposed for use by L-DEO is quite different from sonars used for navy operations. Pulse duration of the multi-beam sonar is very short relative to the naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the multi-beam sonar for much less time given the generally downward orientation of the beam and its narrow fore-aft beam width. (Navy sonars often use near-horizontally-directed sound.) These factors would all reduce the sound energy received from the multi-beam sonar rather drastically relative to that from the sonars used by the Navy.

(c) Possible Effects of Pinger Signals

A pinger will be operated during all dredging, to monitor the depth of the dredging operations relative to the sea floor. Sounds from the pinger are very short pulses, occurring for 1 ms once every second, with source level 193 dB re 1 µPa·m. Most of the energy in the sound pulses emitted by this pinger is at mid frequencies, centered at 12 kHz. The signal is omnidirectional. The pinger produces sounds that are within the range of frequencies used by small odontocetes (killer whales, Pacific white-sided dolphins, and Dall's porpoise) and pinnipeds (harbor seals and Steller sea lions) that occur or may occur in the area of the planned surveys.

Masking

Whereas the pinger produces sounds within the frequency range used by odontocetes that may be present in the survey area and within the frequency range heard by pinnipeds, marine mammal communications will not be masked appreciably by the pinger signals. This is a consequence of the relatively low power output, low duty cycle, and brief period when an individual mammal is likely to be within the area of potential effects. In the case of mysticetes, the pulses do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the pinger are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the pinger are much weaker than those from the bathymetric sonars and from the GI gun. Therefore, behavioral responses are not expected unless marine mammals are very close to the source.

NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". The vessel will be nearly stationary during dredging, so marine mammals could be exposed to signals from the pinger for longer periods than while the vessel is underway. However, even that length of exposure would not result in a "take" by harassment because of the strength of the signal.

Hearing Impairment and Other Physical Effects

Source levels of the pinger are much lower than those of the GI gun and bathymetric sonars, which are discussed above. It is unlikely that the pinger produces pulse levels strong enough to cause temporary hearing impairment or (especially) physical injuries even in an animal that is (briefly) in a position near the source.

Sea Turtles

It is very unlikely that pinger operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. The frequency of the pinger signals is well above the range of optimum hearing in sea turtles (see Appendix B). If there are any effects, they would be negligible given the frequency and low duty cycle, the likely brief exposure, and the relatively low source level

(d) Numbers of Marine Mammals that Might be "Taken by Harassment"

All anticipated takes would be "takes by harassment" as described in § V, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix A, there is no specific information demonstrating that

injurious "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate "take by harassment" and present estimates of the numbers of marine mammals that might be affected during the proposed seismic study in the Aleutian Islands. The estimates are based on data obtained during marine mammal surveys in and near the Aleutian Islands by Brueggeman et al. (1987, 1988), Troy and Johnson (1989), Dahlheim et al. (2000), Waite et al. (2002), Doroff et al. (2003), Wade et al. (2003), Waite (2003), and Tynan (2004), and on estimates of the size of the areas where effects could potentially occur.

This section provides two types of estimates: estimates of the number of potential "exposures" to sound levels ≥160 and/or ≥170 dB re 1 µPa (rms), and estimates of the number of different individual marine mammals that might potentially be exposed to such levels. The ≥160 dB criterion is applied for all species of cetaceans and pinnipeds; the ≥170 dB criterion is applied for delphinids, Dall's porpoise, and pinnipeds (where possible). Based on evidence summarized in § VII(a), the 160 dB criterion is considered appropriate for cetaceans other than delphinids and Dall's porpoise, whereas the 170 dB criterion is considered more appropriate for delphinids, Dall's porpoise, and pinnipeds, which tend to be less responsive.

The number of different individual mammals exposed to a given sound level is lower than the calculated number of exposures. When marine mammals are present near overlapping or intersecting survey lines, some of the same individuals are likely to be approached by the GI gun on more than one occasion. The distinction between "exposures" and "number of different individuals exposed" is less important in this project than in some other projects because this survey does not call for repeated operations through the same or adjacent waters, unless a survey line is repeated because of poor data quality. However, if a survey line is repeated, any animals that react to airgun sounds by moving away from the source are not likely to be present and affected during the second survey of that line. This would result in some overestimation of the number of exposures, given that the density of marine mammals in the area in the absence of seismic surveys is assumed to apply throughout the seismic survey.

The distinction between the number of *exposures* and the number of *different individuals exposed* has been recognized in estimating numbers of "takes" during some previous seismic surveys conducted under IHAs (e.g., Harris et al. 2001; Moulton and Lawson 2002), including various L-DEO projects (Smultea and Holst 2003; Haley and Koski 2004; MacLean and Haley 2004; Smultea et al. 2004). Estimates of the number of exposures are considered precautionary *overestimates* of the actual numbers of different individuals potentially exposed to seismic sounds, because in all likelihood, exposures include repeated exposures of some of the same individuals.

Although several systematic surveys of marine mammals have been conducted in the Aleutians, southern Bering Sea, and northern GOA, few data are available on the numbers and distributions of marine mammals in the western Aleutian Islands. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection. There is some uncertainty about the representativeness of those data and the assumptions used below to estimate the potential "take by harassment", especially as applied to the western part of the study area. However, the approach used here seems to be the best available approach.

The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by 5139 line kilometers of seismic surveys with the single GI gun around the Aleutian Islands. The 5139 km includes a 25% allowance over and above the planned 4112 km to allow for turns, lines that might have to be repeated because of poor data quality, or for minor changes to the survey design. The anticipated radii of influence of the bathymetric sonars and sub-bottom profiler are

less than those for the single GI gun. It is assumed that, during simultaneous operations of those additional sound sources and the single GI gun, any marine mammals close enough to be affected by the sonar or profiler would already be affected by the GI gun. No animals are expected to exhibit more than short-term and inconsequential responses to the sonar or pinger given their characteristics (e.g., narrow downward-directed beam) and other considerations described in §I and in §VII(b,c) above. Such reactions are not considered to constitute "taking" (NMFS 2001). Therefore, no additional allowance is included for animals that might be affected by the sound sources other than the single GI gun. For similar reasons, any effects of the bathymetric sonars or pinger during times when one or more of them are operating but the GI gun is silent are not considered.

Basis for Estimating "Take by Harassment"

Numbers of marine mammals that might be present and potentially disturbed are estimated below based on available data about mammal distribution and densities in the area. The main sources of numerical information about numbers and densities of marine mammals in the area are summarized here:

Cetaceans

Although several systematic surveys of marine mammals have been conducted in the Aleutians, southern Bering Sea, and northern GOA, few data are available on the numbers and distributions of marine mammals in the western Aleutian Islands. Tynan (2004) conducted surveys for fin and humpback whales and Dall's and harbor porpoises in the shelf and slope waters of the southeast Bering Sea, and reported sightings of other cetaceans. Wade et al. (2003) conducted surveys of killer whales and other marine mammals throughout the Aleutian Islands. Waite (2003) conducted surveys for killer whales and other marine mammals in the eastern Aleutian Islands and the northern GOA. Waite et al. (2002) studied the occurrence and distribution of killer whales in the Bering Sea. Dahlheim et al. (2000) examined harbor porpoise densities around the Alaskan Peninsula. Forney and Brownell (1996) conducted surveys for cetaceans in the eastern Aleutian Islands. Troy and Johnson (1989) reported on the densities of small cetaceans (and pinnipeds) in nearshore areas (<100 m deep) along the northern Aleutian shelf. Finally, Brueggeman et al. (1987, 1988) conducted aerial surveys in the northwest GOA and southeastern Bering Sea during 1985 and ship surveys in the GOA in 1987.

As noted above, there is some uncertainty about the representativeness of the data and the assumptions used in the calculations. Some of the survey data are very old (Brueggeman et al. 1987, 1988) and/or the surveys were conducted in areas adjacent to the proposed seismic survey rather than in the area where the seismic surveys will be conducted (Forney and Brownell 1996; Waite 2003). Only the data of Wade et al (2003) were obtained primarily in our proposed survey area. Data are especially limited for the western Aleutians. However, the approach used here is believed to be the best available approach. To provide some allowance for the uncertainties, "maximum estimates" as well as "best estimates" of the numbers potentially affected have been derived. For most cetacean species, seven density estimates were available for combined slope (100–1000 m deep) and offshore (>1000 m) areas, and two estimates were available for shallow nearshore waters (<100 m deep). For those species and areas, the "maximum density" was the highest density recorded during any one of surveys. Best estimates are based on the average densities calculated from the data reported in the studies described above. The average density is calculated by weighting the densities from individual surveys according to the effort (in km) during that survey.

Table 5 gives the average and maximum densities for each cetacean species or species group reported to occur in the Aleutian Islands in waters >100 m deep, corrected for effort, based on the

TABLE 5. Densities and their CVs for cetaceans sighted during surveys in the southeast Bering Sea, Aleutian Islands, and western Gulf of Alaska during 1984–2003. Densities are estimated from sighting and effort data in Brueggeman et al. (1987, 1988), Forney and Brownell (1996), Dahlheim et al. (2000), Waite et al. (2002), Waite (2003), Wade et al. (2003), and Tynan (2004), and are based on both aerial and ship transect surveys. Densities are corrected for $f(0)$ and $g(0)$ biases based on Koski et al. (1998), Barlow (1999), and, where available, the study that provided the data. Species listed as endangered are in italics.

Species	Average Density ($\#/km^2$)		Maximum Density ($\#/km2$)	
	Density	CV [a]	Density	CV
Odontocetes				
Sperm whale	*0.0005*	*0.28*	*0.0022*	*0.36*
Cuvier's beaked whale	0.0035	0.76	0.0036	0.94
Baird's beaked whale	0.0011	0.55	0.0041	0.60
Stejneger's beaked whale	0.0000	—	0.0000	—
Beluga	0.0000	—	0.0000	—
Pacific white-sided dolphin	0.0014	0.57	0.0129	0.83
Risso's dolphin	0.0000	—	0.0000	—
Killer whale [b]	0.0146	0.14	0.0458	0.60
Short-finned pilot whale	0.0000	—	0.0000	—
Phocoenidae				
Harbor porpoise [c]	0.0135	0.10	0.1111	0.18
Dall's porpoise	0.1193	<0.05	0.2622	0.08
Mysticetes				
North Pacific right whale	*0.0000*	*0.76*	*0.0008*	*0.83*
Gray whale	0.0111	<0.05	0.0262	<0.05
Humpback whale	*0.0171*	*<0.05*	*0.0354*	*<0.05*
Minke whale	0.0039	0.15	0.0107	0.20
Sei whale	*0.0000*	*0.83*	*0.0003*	*0.83*
Fin whale	*0.0132*	*<0.05*	*0.0351*	*0.29*
Blue whale	*0.0000*	*—*	*0.0000*	*—*

[a] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation $0.94 - 0.162\log_e n$ from Koski et al. (1998), but likely underestimates the true variability.

[b] Includes surveys in the SE Central Bering Sea in 1999 and 2000 (Waite et al. 2002)

[c] Includes surveys in Bristol Bay in 1991 and the Alaska Peninsula in 1992 (Dalheim 2000)

sightings and effort data from the above reports. The data in Troy and Johnson (1989) were excluded because they included primarily waters <50 m deep and only limited survey effort in 50–100 m depths. Less than 0.01% of the planned survey will be conducted in water depths <50 m and <1% will be conducted in water depths 50–100 m. The densities calculated from sightings during the studies have

been adjusted (where needed) using correction factors from Koski et al. (1998) and Barlow (1999), for both detectability and availability biases. Detectability bias, quantified in part by $f(0)$, is associated with diminishing sightability with increasing lateral distance from the trackline. Availability bias [$g(0)$] refers to the fact that there is <100% probability of sighting an animal that is present along the survey trackline.

The estimated numbers of potential exposures and individuals exposed are presented separately below, based on the 160 dB and, for delphinids and Dall's porpoise, 170 dB re 1 µPa (rms) criteria. It is assumed that marine mammals exposed to GI gun sounds that strong might change their behavior sufficiently to be considered "taken by harassment" (see § I and Table 1 for a discussion of the origin of the potential disturbance isopleths).

Pinnipeds

Population sizes of pinnipeds that congregate at haul-out sites or rookeries are usually estimated based on counts or photographs of the animals on those sites at the time of year when peak numbers are hauled out. Depending on the species and study, a correction factor for the proportion of animals hauled out at any one time may or may not have been applied (depending whether they were available for the particular species and area) so that a total population size can be estimated. Shipboard or aerial surveys have provided some data on distribution at sea, but attempts to estimate total numbers of pinnipeds in open water based on survey data are rare and the only major studies that have reported pinniped sightings during ship and aerial surveys are by Brueggeman (1987, 1988). Other pinniped surveys in the Aleutian Islands typically have estimated the number of animals at haulout sites, not in the water. Only the animals in the water would be exposed to the pulsed sounds from the GI gun (and sonars) so we have used the surveys by Brueggeman et al. (1987, 1988) to estimate numbers of pinnipeds that would be in the water at the time of the proposed seismic survey.

The Steller sea lion population that occurs in the vicinity of the proposed survey has declined dramatically since the surveys by Brueggeman et al. (1987, 1988). Therefore, the densities of Steller sea lions that were calculated from sightings during the Brueggeman et al. (1987, 1988) surveys have been reduced in proportion to the population declines between the survey year and 2004. In 1977, the Steller sea lion population was estimated at 109,880 adults and juveniles (Angliss and Lodge 2004), and in 2004 the number of adults and juveniles was ~21,933 (Fritz 2004). Although the other pinniped populations have declined during the same period, the declines have not been as well documented and appear to have been smaller, so the densities for other species of pinnipeds were not adjusted. The densities of those species are likely to be overestimates of the numbers that will be encountered during the proposed survey, but the degree of overestimation is unknown.

Counts of Steller sea lions are conducted on rookeries and haulouts throughout their range every year in June and July, when the maximum numbers of sea lions are hauled out (e.g., Sease et al. 2001). The timing of maximum haulout and of the counts coincides with the timing of the proposed surveys. At that time of year, minimum numbers of Steller sea lions will be in the water where they potentially could be affected by seismic sounds. Sea lions appear to spend more time in the water during the winter than they do during the breeding season. Sease and York (2003) counted approximately half the number of sea lions during winter surveys compared to the breeding-season surveys. They determined that the difference was primarily a function of sea lions dispersing to local haulout sites during the winter, rather than large-scale movements. There may also be differences in the proportion of time that different age or sex classes spend in the water or hauled out. Trites and Porter (2002) reported that lactating females may spend as little as 24% of their time on shore. Mature females without dependent offspring, adult males, and weaned juveniles probably have different foraging strategies than lactating females, and spend different proportions of their

time ashore. Even for a haulout site close to a part of the seismic survey, not all of the animals that are in the water would be near the seismic operation; most would be dispersed some distance from the haulout. The density of sea lions in the water presumably would decrease as distance from the haulout increased.

The abundance of harbor seals in Alaska was determined by aerial surveys of haul-outs in 1994 and 1996 (e.g., Withrow and Loughlin 1995) and in 2001 (Withrow and Cesarone 2002). The counts were conducted during the summer and early fall (August–September), when the maximum number of harbor seals are hauled out during the molt, and the counts cover every known haulout in the areas surveyed. No counts were available for harbor seals in the Aleutians during the 2001 survey, so the data from 1994 and 1996 were used to estimate the size of the Gulf of Alaska stock (Angliss and Hodge 2004). The number of harbor seals in the GOA stock, which includes the Aleutian Islands, was estimated to be 29,175 with an allowance for seals at sea during the census period (Angliss and Lodge 2004). The correction factor used to adjust for seals at sea was obtained during earlier years, and may not be appropriate for the 1994 and 1996 survey (Angliss and Hodge 2004). The only data on the densities of harbor seals at sea are provided by Brueggeman et al. (1987, 1988), and those data were used to estimate numbers of harbor seals that might be encountered during the proposed seismic survey. No corrections have been made for apparent population declines in harbor seals between the Brueggeman et al. (1987, 1988) surveys and the present, so the densities used are probably overestimates of the densities that are likely to be encountered. Harbor seals generally have a small home range (Lowry et al. 2001) and do not disperse long distances, particularly during the molt. Therefore, only harbor seals from haulout areas near the planned seismic surveys likely would be exposed to seismic sounds.

Potential Number of Cetacean "Takes by Harassment" Based on "Exposures"

Best and Maximum Estimates of "Exposures" to ³160 dB

The potential number of *occasions* when members of each species might be exposed to received levels ≥160 dB re 1 µPa (rms) was calculated for each of three water depth categories (<100 m, 100–1000 m, and >1000 m) by multiplying

- the expected species density, either "average" (i.e., best estimate) or "maximum", corrected as described above, times

- the anticipated total line-kilometers of operations with the one GI gun in each water-depth category after allowance for 25% additional line kilometers to allow for GI gun operations during turns and repetition of lines because of equipment malfunction, bad weather, etc., times

- the cross-track distances within which received sound levels are predicted to be ≥160 dB for each water-depth category (Table 1).

For the GI gun, the cross track distance is $2 \times$ the predicted 160 dB radius of 750 m for water depths <100 m, 2×413 m for water depths of 100–1000 m, and 2×275 m for water depths >1000 m. The numbers of exposures in the three depth categories were then summed for each species. Applying the approach described above, ~2742 km² would be within the 160 dB isopleth. We allowed a 25% contingency for GI gun operations during turns and for lines that might be surveyed more than once, so the number of exposures is calculated based on 3427 km².

Based on this method, the "best" and "maximum" estimates of the number of marine mammal exposures to GI gun sounds with received levels ≥160 dB re 1 µPa (rms) were obtained using the average and "maximum" densities from Table 5. The estimates show that three endangered cetacean species may be exposed to such noise levels (unless they avoid the approaching survey vessel before the received levels reach 160 dB). For

convenience, we refer to either eventuality as an "exposure". Our respective best and maximum estimates for those species are as follows: sperm whale, 2 and 8 exposures; humpback whale, 58 and 121 exposures; and fin whale, 45 and 120 exposures (Table 6). Three additional endangered cetacean species that theoretically might be encountered in the area are unlikely to be exposed. Sei, blue, and North Pacific right whales occasionally occur in the area, but given their low "best estimates" of densities in the area, none are expected to be exposed to ≥160 dB given the planned levels of seismic survey effort in the three depth strata. Maximum estimates of exposures for these species are 1, 0, and 3, respectively.

Most of the "exposures" to seismic sounds ≥160 dB would involve phocoenids (mostly Dall's porpoises). Best and maximum estimates of the number of exposures of cetaceans, in descending order, are Dall's porpoise (409 and 898 exposures), killer whale (50 and 157 exposures), and harbor porpoise (46 and 381). Estimates for other species are lower (Table 6). However, as noted earlier, the 160 dB criterion is probably not appropriate as a criterion for disturbance to dolphins and Dall's porpoise. Most of them are unlikely to show appreciable behavioral disturbance unless exposed to stronger sounds.

The far right column in Table 6, "Requested Take Authorization", shows the numbers for which "take authorization" is requested. For the common species, the requested numbers are calculated as indicated above, based on the maximum densities calculated from the data reported in the different studies mentioned above. In some cases, the requested numbers are somewhat higher than the maximum estimated numbers of exposures found in Column 2 of Table 6. Some of the marine mammal species that are known or suspected to occur at least occasionally in the Aleutian Islands were not recorded during the systematic surveys that were used to estimate densities. In those cases, the "Requested Take Authorization" figures include upward adjustments for small numbers that might be encountered even though they were not recorded during the surveys mentioned above.

Best and Maximum Estimates of Delphinid and Dall's Porpoise Exposures to ³170 dB

The 160 dB criterion on which the preceding estimates are based was derived from studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive, and delphinids generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix A (e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB (rms). There is no generally accepted alternative "take" criterion for dolphins exposed to airgun sounds. However, our estimates assume that only those dolphins exposed to ≥170 dB re 1 µPa (rms), on average, would be affected sufficiently to be considered "taken by harassment". ("On average" means that some individuals might react significantly upon exposure to levels somewhat <170 dB, but others would not do so even upon exposure to levels somewhat >170 dB.) As such, the best and maximum estimates of the numbers of exposures to ≥170 dB for the two most common delphinid species would be as follows: Pacific white-sided dolphin, 2 and 14, and killer whale, 16 and 51. No other delphinids are expected to be exposed to ≥170 dB, given the limited survey coverage and the rarity of other delphinids in the area (Table 6). Dall's porpoise are also unlikely to react to seismic sounds <170 dB, and the best and maximum number of exposures of Dall's porpoise to ≥170 dB are expected to be 133 and 292, respectively. The values are considered to be more realistic estimates of the numbers of occasions when delphinids and Dall's porpoise may be affected. However, actual 170 dB radii are probably somewhat less than those used to estimate exposures in deep and perhaps intermediate depths, so the numbers of exposures to ≥170 dB may be overestimates. Both Pacific white-sided dolphins and Dall's porpoises are attracted to vessels to bow ride, and densities used to calculate exposures may be positively biased. If those species react differently to the seismic vessel than the survey vessel, the above estimates of exposure to ≥170 dB may be either underestimated or overestimated.

TABLE 6. Estimates of the possible numbers of marine mammal "exposures" to the different sound levels, and the numbers of different individuals that might be exposed, during L-DEO's proposed seismic program in the Aleutian Islands in June–July 2005. The proposed sound source is a single GI gun with injector volume of 105 in^3. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration). Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Delphinids, Dall's porpoise, and pinnipeds are unlikely to react to levels below 170 dB. Species in italics are listed under the U.S. ESA as endangered. The column of numbers in boldface shows the numbers of "takes" for which authorization is requested.[a]

Species	Number of Exposures to Sound Levels ≥160 dB (≥170 dB, Less Responsive Groups)		Number of Individuals Exposed to Sound Levels ≥160 dB (≥170 dB, Less Responsive Groups)[b]				Requested Take Authorization
			Best Estimate				
	Best Estimate	Maximum Estimate	Number	% of Regional Pop'n[c]	Maximum Estimate		
Physeteridae							
Sperm whale	2	8	2	0.0	7		**8**
Ziphiidae							
Cuvier's beaked whale	12	12	11	0.1	11		**12**
Baird's beaked whale	4	14	3	0.1	13		**14**
Stejneger's beaked whale	0	0	0	0.0	0		**5**
Monodontidae							
Beluga	0	0	0	NA	0		**5**
Delphinidae							
Pacific white-sided dolphin	5 (2)	44 (14)	4 (1)	0.0	41 (13)		**44**
Risso's dolphin	0 (0)	0 (0)	0 (0)	0.0	0 (0)		**5**
Killer whale	50 (16)	157 (51)	46 (15)	3.1	144 (47)		**157**
Short-finned pilot whale	0 (0)	0 (0)	0 (0)	0.0	0 (0)		**10**
Phocoenidae							
Harbor porpoise	46	381	43	0.1	350		**381**
Dall's porpoise	409 (133)	898 (292)	376 (122)	0.1	827 (269)		**898**
Balaenopteridae							
North Pacific right whale	0	3	0	0.0	3		**3**
Gray whale	38	90	35	0.1	83		**90**
Humpback whale	58	121	54	0.9	112		**121**
Minke whale	13	37	12	0.8	34		**37**
Sei whale	0	1	0	NA	1		**5**
Fin whale	45	120	42	0.4	111		**120**
Blue whale	0	0	0	0.0	0		**5**
Pinnipeds							
Northern fur seal	4 (1)	24 (8)	3 (1)	0.0	22 (7)		**24**
Steller sea lion	37 (12)	95 (31)	34 (11)	0.1	87 (28)		**95**
Harbor seal	61 (20)	160 (52)	56 (18)	0.2	148 (48)		**148**
Ribbon seal	0 (0)	0 (0)	0 (0)	0.0	0 (0)		**5**

[a] Best estimate and maximum estimates of density are from Table 5.

[b] Estimates of the number of exposures would be about 1.15 × the number of individuals exposed if there were no allowance for lines that might be resurveyed due to poor data quality. There is no overlap of the 160 or 170 dB received noise level radii between adjacent survey lines.

[c] Regional population size estimates are from Table 4.

[d] NA indicates that regional population estimates are not available.

Number of Individual Cetaceans That Might be Exposed to ³160 and ³170 dB

The preceding text estimates the number of occasions when cetaceans of various species might be *exposed* to sounds from the GI gun with received levels ≥160 or ≥170 dB re 1 µPa (rms), including cases where the animals show avoidance before coming within the 160 or 170 dB zone. In contrast, the following section estimates the number of different *individuals* that might potentially be subjected to such received levels on one or more occasions. There is no overlap of the seismic lines planned for this project. Nonetheless, some of the mammals in the project area may be disturbed more than once if lines are resurveyed because of poor data quality. Thus, the total numbers of individuals disturbed one or more times may be *lower* than those calculated above based on the number of exposures.

The number of *different individuals* likely to be exposed to airgun sounds with received levels ≥160 or 170 dB re 1 µPa (rms) on one or more occasions can be estimated by considering the total marine area that would be within the 160 or 170 dB radius around the operating GI gun on at least one occasion. The total area ensonified included allowance for turns and a provision for resurveying a line if the data quality were poor. The area that will be exposed one or more times is unknown, but we will assume that 40% of the additional allowance of 25% (i.e., 10% of the original survey km) represents lines that will be surveyed more than once simply the survey area without allowance for repeated coverage of some lines. For each species, the original estimate of the latter area that would be ensonified was multiplied by 1.15 and that area was multiplied by the marine mammal density, thus estimating the minimum number of marine mammals that would be exposed to ≥160 or ≥170 dB on one or more occasions. These estimates are presented in Table 6 as the *"Number of Individuals Exposed to Sound Levels ≥160 dB (≥170 dB)"*.

This approach does not allow for turnover in the mammal populations in the study area during the course of the study, and thus it might somewhat underestimate actual numbers of individuals exposed to ≥160 and ≥170 dB. However, during this project, operations at each site will be relatively brief (no more than a few days). Also, any tendency for underestimation that might occur is at least partly offset by the likely overestimation of 160 and 170 dB radii during the ~99% of operations that will be conducted in water depths >100 m.

Estimated Numbers of Individuals Exposed to ³160 dB

Estimates of the number of different individuals of each species that might be exposed to ≥160 dB, adjusted for overlap, are provided in Table 6 based on the reported average and maximum densities. As an example, the estimated number of different individual humpback whales that might be exposed to ≥160 dB would be 54 or 112, derived by multiplying the estimated 58 or 121 exposures by 0.92 (1.15÷1.25, where 0.10 is the additional allowance for lines that might be resurveyed and 0.15 is the allowance for seismic shot between lines) (Table 6). Estimated numbers of individuals for the other endangered cetaceans that might be exposed to the sound levels are 2–7 sperm whales, and 42–111 fin whales. For the most common cetacean species, the corresponding estimated numbers of individuals exposed to ≥160 dB are 376–827 Dall's porpoises, 43–350 harbor porpoises, 4–41 Pacific white-sided dolphins, and 46–144 killer whales. However, as previously discussed, the 160 dB criterion is probably inappropriate for white-sided dolphins, killer whales, and Dall's porpoise.

Estimated Numbers of Delphinids and Dall's Porpoises Exposed to ³170 dB

Applying the method described above to the common delphinids, the estimated numbers of individuals exposed to sounds from the GI gun with levels ≥170 dB are 1–13 Pacific white-sided dolphins and 15–47 killer whales (Table 6). The corresponding numbers for Dall's porpoise are 122–269. These

values are based on the predicted 170 dB radii around the GI gun proposed for use. They are believed to be more realistic estimates of the numbers of delphinids that might be affected by the proposed activities.

Potential Number of Pinnipeds that Might be Affected

As discussed above, there are few survey data that document pinniped distribution and densities while they are in the water. The most comprehensive surveys were conducted by Brueggeman et al. (1987, 1988), and data from those surveys have been used to estimate numbers of pinnipeds that might be affected by the single GI gun.

Harbor Seals

Harbor seal populations in the Aleutians are thought to have declined between 1985–1987 and the present, but no quantitative data are available (Angliss and Hodge 2004). In the absence of population trend data, we have used the densities from the Brueggeman et al. (1987, 1988) surveys, with adjustments for availability and detectability bias from Koski et al. (1998), to estimate numbers that might be affected by the proposed survey. Those estimates are overestimates if the populations have actually declined as suggested DeMaster (1996). Best and maximum estimates of 61 and 160 harbor seal exposures to GI gun sounds ≥160 re 1 µPa (rms) may occur during the seismic survey in the western Aleutian Islands (Table 6), and 56 and 148 individual harbor seals might be exposed to those sound levels. Based on the limited responses of many pinnipeds to airgun sounds, 170 dB re 1 µPa (rms) is a better estimate of the sound level that is required to cause changes in pinniped behavior. On that basis, 18 (best estimate) to 48 (maximum estimate) individual harbor seals might be exposed on 20 to 52 occasions during the proposed survey.

Steller Sea Lions

As described earlier, Steller sea lion populations are though to have declined from 109,880 adult and juvenile animals in the late 1970s (we assume 1977) to 30,525 in 1990 (Angliss and Hodge 2004). Numbers continued to decline to 18,325 adults and juveniles in 2000, and since then, they have recovered to about 21,933 in 2004 (preliminary data of Fritz 2004). Assuming a steady decline from 1977 to 1990, the population levels were ~49,598 in 1985 and ~41,023 in 1987. To adjust densities of Steller sea lions derived from the Brueggeman et al. (1987, 1988) surveys for the population declines, we multiplied corrected densities from 1985 surveys (Brueggeman et al. 1987; Koski et al. 1998) by 21,933/49,598 and those from 1987 surveys (Brueggeman et al. 1988) by 21,933/41,023. Based on the resulting densities, best and maximum estimates of 37 and 95 Steller sea lion exposures to GI gun sounds ≥160 re 1 µPa (rms) may occur during the seismic survey in the western Aleutian Islands (Table 6), and 34 and 87 individuals might be exposed to those sound levels. However, we assume that 170 dB re 1 µPa (rms) is a better estimate of the sound level that is required to cause changes in pinniped behavior; 11 (best estimate) to 28 (maximum estimate) individual Steller sea lions might be exposed to ≥170 dB on 12 to 31 occasions during the proposed survey.

Northern Fur Seal

The same procedure as described above for harbor seals was applied to northern fur seal densities calculated from surveys conducted by Brueggeman et al. (1987, 1988). Based on the resulting densities, the best and maximum estimates are 4 and 24 northern fur seal exposures to GI gun sounds ≥160 re 1 µPa (rms) (Table 6), and 3 and 22 individuals might be exposed to those sound levels. Based on the more reasonable 170 dB re 1µPa (rms) criterion, the number of different individuals that might be exposed would be 1 (best estimate) to 7 (maximum), with exposures on 1 to 8 occasions during the proposed survey.

Other Pinniped Species

For ribbon seals, our best estimate of the number of individuals that might be affected by the seismic survey is 0, because they usually do not occur in the study area during June and July. However, the "*Requested Take Authorization*" for ribbon seals is listed as 5 individuals, to allow for the possibility that a few individuals might be encountered.

Conclusions

The proposed survey in the Aleutian Islands will involve towing a single GI gun that introduces pulsed sounds into the ocean, along with simultaneous operation of a multi-beam sonar and hydrographic echo sounder, and the use of a pinger and acoustic positioning system during scientific rock dredging. Routine vessel operations, other than the proposed operations by the single GI gun, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". For similar reasons, no "taking" is expected when the vessel is conducting scientific rock dredging. No "taking" of marine mammals is expected in association with operations of the sonars given the considerations discussed in § I and § VII(b,c), i.e., sonar sounds are beamed downward, the beam is narrow, at least in the fore-aft direction, the pulses are extremely short, and (for the 95-kHz multi-beam) absorption in seawater is rapid.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels operating large arrays of airguns have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel. However, reactions at the longer distances appear to be atypical of most species and situations, particularly when feeding whales are involved (Miller et al. in press). Many of the mysticetes that will be encountered in the Aleutian Islands at the time of the proposed seismic survey will be feeding. In addition, the single GI gun to be used in this project is a much less powerful source than were the sources eliciting avoidance at distances of several kilometers or more. Furthermore, the estimated 160 and 170 dB radii used here are probably overestimates of the actual 160 and 170 dB radii at water depths =100 m based on the few calibration data obtained in deep water (Tolstoy et al. 2004a,b). Thus, the estimated numbers presented in Table 6 are most likely to overestimate actual numbers.

Odontocete reactions to seismic pulses, or at least the reactions of delphinids and Dall's porpoise, are expected to occur at lesser distances from the GI gun than are those of mysticetes. Odontocete low-frequency hearing is less sensitive than that of mysticetes, and delphinids and Dall's porpoise are often seen from seismic vessels. In fact, there are documented instances of delphinids and Dall's porpoise approaching active seismic vessels. However, delphinids and some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior when near operating seismic vessels.

Taking into account the small size and relatively low sound output of the single GI gun to be used, and the mitigation measures that are planned, effects on cetaceans are generally expected to be limited to avoidance of a small area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are very low percentages of the population sizes in the northeast Pacific Ocean, as described below.

Based on the 160 dB criterion, the *best estimates* of the numbers of *individual* cetaceans that may be exposed to sounds ≥160 dB re 1 µPa (rms) represent 0–3.1% of the populations of each species in the northeast Pacific Ocean (Table 6). The assumed population sizes used to calculate those percentages are presented in Table 4. For species listed as ***Endangered*** under the ESA, our estimates include no North

Pacific right whales, sei whales, or blue whales; <0.1% of the northeast Pacific Ocean population of sperm and sei whales; 0.9% of the humpback whale population; 0.8% of the minke whale population; and 0.4% of the fin whale population (Table 6). In the cases of belugas, beaked whales, and sperm whales, the potential reactions are expected to involve no more than very small numbers (0 to 13) of individual cetaceans. Humpback and fin whales are the ***Endangered*** species that are most likely to be exposed, and their northeast Pacific Ocean populations are ~6000 (Carretta et al. 2002) and 10,970 (Ohsumi and Wada 1974), respectively.

It is highly unlikely that any North Pacific right whales will be exposed to seismic sounds ≥160 dB re 1 µPa (rms), but based on the maximum densities observed, 3 North Pacific right whales might be exposed during the proposed survey. This conclusion is based on the rarity of this species in Alaska and the northeast Pacific Ocean (<100, Reeves et al. 2002; Mellinger et al. 2004; Table 5), and on the fact that the remnant population of this species apparently migrates to the Gulf of Alaska, which is east of the proposed survey area, for the summer. However, some right whales have been seen in the SE Bering Sea during summer (Tynan 2003), and so right whales might be encountered. Therefore, we request authorization to expose up to three North Pacific right whales to ≥160 dB, given the possibility (however unlikely) of encountering one or more of this endangered species. If a right whale is sighted by the vessel-based observers, the GI gun will be shut down regardless of the distance of the whale from the gun.

Low to moderate numbers of phocoenids and delphinids may be exposed to sounds produced by the single GI gun during the proposed seismic studies, but the population sizes of species likely to occur in the operating area are large, and the numbers potentially affected are small relative to the population sizes (Table 6). The best estimates of the numbers of *individual* Dall's and harbor porpoises that might be exposed to ≥160 dB represent 0.1% of their northeast Pacific Ocean populations. Killer whales are expected to be relatively abundant in the proposed survey area, and 3.1% of the Alaskan population might be exposed to seismic sounds to ≥160 dB. However, because killer whale hearing is thought to be relatively poor at the dominant frequencies produced by a GI gun, the proportion exposed to ≥170 dB (1.0%) is thought to be more relevant for killer whales (and other delphinids). Excluding the killer whale, the best estimates of the numbers of *individual* delphinids that might be exposed to sounds ≥170 dB re 1 µPa (rms) represent <<0.01% of the ~600,000 dolphins estimated to occur in the Northeast Pacific, and <0.1% of the population of each species occurring there (Table 6). Dall's porpoise are the most abundant cetacean that is expected to be exposed, but like delphinids, their hearing is thought to be relatively poor at the dominant frequencies produced by a GI gun. The 122 individual Dall's porpoises expected to be exposed to ≥170 dB is <<0.1% of the Northern Pacific population of about 417,000 animals (Table 4).

Varying estimates of the numbers of marine mammals that might be exposed to sounds from the single GI gun during the 2005 seismic survey in the Aleutian Islands have been presented, depending on the specific exposure criteria (≥160 *vs.* ≥170 dB), calculation procedures (exposures *vs.* individuals), and density criteria used (best *vs.* maximum). The requested "take authorization" for each species is based on the estimated *maximum number of exposures* to ≥160 dB re 1 µPa (rms), i.e., the highest of the various estimates. That figure *likely overestimates* the actual number of animals that will be exposed to the sound levels; the reasons for this are outlined above. Even so, the estimates for the proposed surveys are quite low percentages of the population sizes. The relatively short-term exposures are not expected to result in any long-term negative consequences for the individuals or their populations.

The many cases of apparent tolerance by cetaceans of seismic exploration, vessel traffic, and some other human activities show that co-existence is possible. Mitigation measures such as controlled speed, course alteration, look outs, non-pursuit, and shut downs when marine mammals are seen within defined

ranges will further reduce short-term reactions, and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Pinnipeds

Two pinniped species (the Steller sea lion and the harbor seal) and the sea otter are likely to be encountered in the study area. Also, it is possible that a small number of northern fur seals may be encountered, and possible (but very unlikely) that a few ribbon seals may be encountered. An estimated 18 individual harbor seals and 11 individual Steller sea lions (<0.1% and 0.1% of their northeast Pacific Ocean populations, respectively) may be exposed to GI gun sounds at received levels ≥170 dB re 1 μPa (rms) during the seismic survey. It is probable that only a small percentage of those would actually be disturbed. It is most likely that only one northern fur seal and no ribbon seals will be exposed to ≥170 dB.

As for cetaceans, the short-term exposures of pinnipeds to GI gun sounds are not expected to result in any long-term negative consequences for the individuals or their populations.

VIII. ANTICIPATED IMPACT ON SUBSISTENCE

> The anticipated impact of the activity on the availability of the species or stocks of marine mammals for subsistence uses.

Subsistence hunting and fishing continue to be prominent in the household economies and social welfare of some Alaskan residents, particularly among those living in small, rural villages (Wolfe and Walker 1987). Subsistence remains the basis for Alaska Native culture and community. In rural Alaska, subsistence activities are often central to many aspects of human existence, including patterns of family life, artistic expression, and community religious and celebratory activities.

Marine mammals are legally hunted in Alaskan waters by coastal Alaska Natives; species hunted include Steller sea lions, ringed seals, ribbon seals, bearded seals, harbor seals, walruses, and sea otters. In the Aleutians, Steller sea lions, harbor seals, sea otters, and small numbers of spotted and ringed seals are hunted (ADFG 1997). In the Aleutians and Pribilof Islands, fur seals and sea lions make up most of the marine mammal harvest in Saint Paul and Saint George (on the Pribilofs); harbor seals and sea lions comprise the majority of takes in Atka, Nikolski, Unalaska, and Akutan; and harbor seals are taken most frequently in False Pass, Sand Point, King Cove, and Nelson Lagoon (ADFG 1997). Hunting communities are concentrated along the Eastern Aleutian Islands, and the project area is close to only two hunting communities, Nikolski (on Umnak Isl.) and Unalaska (Fig. 1).

Steller sea lions are an important subsistence resource for Alaska Natives from SE Alaska to the Aleutian Islands. From 1997 to 2001, an estimated 164–198 sea lions were taken annually by Alaska Natives (Wolfe et al. 2003). Wolfe et al. (2003) noted that most of the 185 sea lions that were taken in 2002 were harvested in the Aleutian Islands (57%) followed by the Pribilof Islands (23%). Hunting communities in the Aleutian Islands include Akkutan, Atka, Nikolski, and Unalaska Islands (Wolfe et al. 2004), where their (estimated and expanded) sea lion harvests during 2002 were ~3, 86, 1 and 16, respectively (ADFG 2003). The 2002 Akutan community harvested half of its sea lions in June and half in August. Atka harvested most of its sea lions in January (~22 animals), and did not harvest any animals in April, June, or July. The community of Nikolski harvested its one sea lion in October, and the community of Unalaska harvested ~7 sea lions in August.

Harbor seals are also an important food sources for Alaskans. From 1997 to 2001, the number of animals taken ranged from 2546 in 1997 to 2031 in 2001 (Wolfe et al. 2003). In 2002, a total of 1834 harbor seals were taken. Most were taken in SE Alaska and the North Pacific Rim; only 3.6% were taken in the Aleutian Islands (Wolfe et al. 2003). In the Aleutian Islands, hunting communities include Akutan, Atka, Nikolski, and Unalaska Islands (Wolfe et al. 2003), where estimated and expanded harbor seal harvests in 2002 were ~10, 36, 4, and 16, respectively (ADFG 2003). Wolfe et al. (2003) reported that overall harbor seal hunting was extremely poor in 2002; takes during the first seven months were the lowest recorded since surveys began in 1992. During 2002, Akutan took an expanded count of ~3 harbor seals in each of January and June, Atka harvested ~8 harbor seals in March, Nikolski harvested 3 harbor seals in September, and Unalaska harvested ~3 harbor seals in each of January, June, September, and October.

The USFWS monitors the harvest of sea otters in Alaska using a mandatory marking, tagging, and reporting program that has been implemented since 1988. The USFWS estimated that, from 1996 to 2000, the average annual harvest from the SW Alaska stock was 97 (Angliss and Lodge 2004). The subsistence harvest of sea otters occurs year–round in coastal communities. However, there is a general reduction in harvest during the summer months (D. Willoya, The Alaska Sea Otter and Steller Sea Lion Commission, pers. comm.). The geographical distribution of the harvest is difficult to determine because reports are generated by marking location; harvest location is generally not recorded (USFWS, unpublished data). Harvests can take place from a large geographic area surrounding each sea otter harvesting village (D. Willoya, pers. comm.).

The subsistence harvest within the planned project area of other marine mammal species is small and irregular.

Spotted seals are mainly hunted in the Bering Strait and Yukon-Kuskokwim region (Angliss and Lodge 2004). From 1993 to 1995, the annual mean subsistence take in northern Bristol Bay was estimated at 244 (Angliss and Lodge 2004). In 2002, 229 spotted seals were taken in northern Bristol Bay (Wolfe et al. 2003). An updated estimate of the number of takes in Alaska is 5265 animals annually (Angliss and Lodge 2004).

Northern fur seals are mainly taken in the Pribilof Islands, although minimal takes in other areas are also thought to occur (Angliss and Lodge 2004). From 1986 to 1996, the harvest averaged 1605 animals annually (Angliss and Lodge 2004). From 1997 to 2001, the average harvest level was 1132 (Angliss and Lodge 2004).

Bearded seals are also hunted in Alaska, but mainly in the Bering Strait region and northward (Angliss and Lodge 2004). In the Bering Strait, it was estimated that 791 bearded seals were taken between August 1985 and June 1986 (Kelly 1988a). The annual mean subsistence take in Alaska is thought to be 6788 bearded seals (Angliss and Lodge 2004).

Ringed seals are also hunted in Alaska, but mainly from St. Lawrence Island and northward; during the mid 1980s, more than 3000 likely were taken (Kelly 1988b). Later estimates indicated a harvest of 9567 ringed seals annually (Angliss and Lodge 2004).

Ribbon seals are taken in Alaska as well, primarily in the Bering Strait, with an estimate of less than 100 seals taken annually (Kelly 1988c). Newer estimates indicate an annual subsistence hunt of 193 ribbon seals (Angliss and Lodge 2004).

Walruses are hunted in Alaska and Chukotka, with a harvest of 5789 animals annually, based on 1996–2000 harvest statistics (Angliss and Lodge 2004). Pacific walruses reach as far south as the Togiak National Wildlife Refuge and Walrus Islands State Game Sanctuary in northern Bristol Bay. They are not

harvested in the area of the proposed study along the Aleutian Chain (Douglas Burn, USFWS Marine Mammal Management Biologist, pers. comm., 16 January 2004).

Beluga whales do not occur regularly within the project area (see §IV). Any occasional subsistence hunting of belugas that might occur in that area would be opportunistic hunting of extralimital animals. From 1996 to 2000, the annual take from the eastern Bering Sea stock and the Bristol Bay stock were 164 and 15 belugas, respectively (Angliss and Lodge 2004).

Gray whales have traditionally been hunted by Alaskans and Russians (Angliss and Lodge 2004). Alaskan natives took 2 gray whales in 1995 (IWC 1997). Some of the gray whales that migrate through SE Alaskan waters in spring and late autumn are hunted in Russian waters during summer, and a very limited subsistence hunt has occurred in recent years off Washington. From 1998 to 2002, Russians and U.S. (Makah Indian Tribe) aboriginals had a yearly quota of 140 gray whales, of which the great majority was for Russians (IWC 1998). The annual subsistence take was 97 whales from 1996 to 2000 (Angliss and Lodge 2004), and only one whale was harvested by the Makah Indian Tribe in 1999 (IWC 2001). Any small-scale disturbance effects that might occur in SW Alaska as a result of L-DEO's project would have no effect on the hunts for gray whales in those distant locations.

Although minke whales typically are not taken, subsistence takes by Alaska Native have occurred in the past (Angliss and Lodge 2004). Seven minke whales were taken between 1930 and 1987, and two whales were taken in 1989 at unreported locations (Anonymous 1991).

In addition, people salvage blubber from beached whales in the Aleutian Islands (ADFG 1997). The project is not expected to harm or kill marine mammals, and it will have no effect on this activity.

The proposed project potentially could impact the availability of marine mammals for harvest in a very small area immediately around the *Kilo Moana*. At any given location, this effect would persist for a only a short time period during seismic activities—probably less than an hour, given the small size of the seismic source to be used in this project. Pinnipeds and sea otters are generally not very responsive to airgun pulses [see §IV(1)(a) and Appendix A]. Considering that, and the limited time and locations for the planned seismic surveys, the proposed project is not expected to have any significant impacts to the availability of Steller sea lions, harbor seals, or sea otters for subsistence harvest.

On average, subsistence fisheries provide about 230 pounds of food per person per year in rural Alaska (Wolfe 2000). Of the estimated 43.7 million pounds of wild foods harvested in rural Alaska communities annually, subsistence fisheries contribute the majority, with ~60% from finfish and ~2% from shellfish. In the numerous rural communities along the GOA, salmon species are the most targeted subsistence fish.

Seismic surveys can, at times, cause changes in the catchability of fish [see § IV(5)(a) in accompanying EA]. L-DEO will minimize the potential for negative impacts on the subsistence fish harvest by avoiding seismic or scientific rock dredging operations in areas where subsistence fishers are fishing. Additionally, L-DEO will consult with each village near the planned project area to identify and avoid areas of potential conflict. These consultations will include all marine subsistence activities (mammal and fish harvests).

IX. ANTICIPATED IMPACT ON HABITAT

> The anticipated impact of the activity upon the habitat of the marine mammal populations, and the likelihood of restoration of the affected habitat.

One of the reasons for the adoption of airguns as the standard energy source for marine seismic surveys was that they (unlike the explosives used in the distant past) do not result in any appreciable fish kill. However, the existing body of information relating to the impacts of seismic on marine fish and invertebrate species is very limited. The various types of potential effects of exposure to seismic on fish and invertebrates can be considered in three categories: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects include lethal and sub-lethal damage to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behavior of the fish and invertebrates. The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to the ultimate pathological effect on individual animals (i.e., mortality).

The available information on the impacts of seismic surveys on marine fish and invertebrates provides limited insight on the effects only at the individual level. Ultimately, the most important knowledge in this area relates to how significantly seismic affects animal populations.

The following sections provide an overview of the information that exists on the effects of seismic surveys on fish and invertebrates. The information comprises results from scientific studies of varying degrees of soundness and some anecdotal information.

Pathological Effects.—In water, acute injury and death of organisms exposed to seismic energy depends primarily on two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay (Hubbs and Rechnitzer 1952 *in* Wardle et al. 2001). Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the pathological zone for fish and invertebrates would be expected to be within a few meters of the seismic source (Buchanan et al. 2004). For the proposed survey, any injurious effects on fish would be limited to very short distances, especially considering the small source planned for use in this project (a single GI gun with a discharge of up to 105 in^3).

Matishov (1992) reported that some cod and plaice died within 48 hours of exposure to seismic pulses 2 m from the source. No other details were provided by the author. On the other hand, there are numerous examples of no fish mortality as a result of exposure to seismic sources (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a, 2000b; Bjarti 2002; IMG 2002; McCauley et al. 2003; Hassel et al. 2003).

There are examples of damage to fish ear structures from exposure to seismic airguns (McCauley et al. 2000a, 2000b, 2003), but it should be noted the experimental fish were caged and exposed to high cumulative levels of seismic energy. Atlantic salmon were exposed within 1.5 m of underwater explosions (Sverdrup et al. 1994). Compared to airgun sources, explosive detonations are characterized by higher peak pressures and more rapid rise and decay times, and are considered to have greater potential to damage marine biota. In spite of this, no salmon mortality was observed immediately after exposure or during the seven-day monitoring period following exposure.

Some studies have also provided some information on the effects of seismic exposure on fish eggs and larvae (Kostyuchenko 1972; Dalen and Knutsen 1986; Holliday et al. 1987; Matishov 1992; Booman

et al. 1996; Dalen et al. 1996). Overall, impacts appeared to be minimal and any mortality was generally not significantly different from the experimental controls. Generally, any observed larval mortality occurred after exposures within 0.5–3 m of the airgun source. Matishov (1992) did report some retinal tissue damage in cod larvae exposed at 1 m from the airgun source. Saetre and Ona (1996) applied a 'worst-case scenario' mathematical model to investigate the effects of seismic energy on fish eggs and larvae, and concluded that mortality rates caused by exposure to seismic are so low compared to natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

The pathological impacts of seismic energy on marine invertebrate species have also been investigated. Christian et al. (2003) exposed adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs to energy from seismic airguns. Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult male and female crabs. There was a significant difference in development rate noted between the exposed and unexposed fertilized eggs. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than the unexposed mass. It should be noted that both egg masses came from a single female and that any measure of natural variability was unattainable. However, a result such as this does point to the need for further study.

Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab to single discharges from a seven-airgun seismic array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to molt, this field experiment did not reveal any statistically-significant differences between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

Bivalves of the Adriatic Sea were also exposed to seismic energy and subsequently assessed (LaBella et al. 1996). No effects of the exposure were noted.

To date, there have not been any well-documented cases of acute post-larval fish or invertebrate mortality as a result of exposure to seismic sound under normal seismic operating conditions. Sub-lethal injury or damage has been observed, but generally as a result of exposure to very high received levels of sound, significantly higher than the received levels generated by the single GI gun sound source to be used in the proposed study. Acute mortality of eggs and larvae have been demonstrated in experimental exposures, but only when the eggs and larvae were exposed very close to the seismic sources and the received pressure levels were presumably very high. Limited information has not indicated any chronic mortality as a direct result of exposure to seismic.

Physiological Effects.—Biochemical responses by marine fish and invertebrates to acoustic stress have also been studied, although in a limited way. Studying the variations in the biochemical parameters influenced by acoustic stress might give some indication of the extent of the stress and perhaps forecast eventual detrimental effects. Such stress could potentially affect animal populations by reducing reproductive capacity and adult abundance.

McCauley et al. (2000a, 2000b) used various physiological measures to study the physiological effects of exposure to seismic energy on various fish species, squid, and cuttlefish. No significant physiological stress increases attributable to seismic energy were detected. Sverdrup et al. (1994) found that Atlantic salmon subjected to acoustic stress released primary stress hormones, adrenaline and cortisol, as a biochemical response although there were different patterns of delayed increases for the different indicators. Caged European sea bass were exposed to seismic energy and numerous biochemical responses were indicated. All returned to their normal physiological levels within 72 hours of exposure.

Stress indicators in the haemolymph of adult male snow crabs were monitored after exposure of the animals to seismic energy (Christian et al. 2003). No significant differences between exposed and unexposed animals were found in the stress indicators (e.g., proteins, enzymes, cell type count).

Primary and secondary stress responses of fish after exposure to seismic energy all appear to be temporary in any studies done to date. The times necessary for these biochemical changes to return to normal are variable depending on numerous aspects of the biology of the species and of the sound stimulus.

Summary of Physical (Pathological and Physiological) Effects.—As indicated in the preceding general discussion, there is a relative lack of knowledge about the potential physical (pathological and physiological) effects of seismic energy on marine fish and invertebrates. Available data suggest that there may be physical impacts on egg, larval, juvenile, and adult stages at very close range. Considering typical source levels associated with commercial seismic arrays, close proximity to the source would result in exposure to very high energy levels. Again, this study will employ a sound source that will generate low energy levels. Whereas egg and larval stages are not able to escape such exposures, juveniles and adults most likely would avoid it. In the case of eggs and larvae, it is likely that the numbers adversely affected by such exposure would not be that different from those succumbing to natural mortality. Limited data regarding physiological impacts on fish and invertebrates indicate that these impacts are short term and are most apparent after exposure at close range.

The only EFH species present as a very early life stage (while unable to avoid seismic exposure) that would possibly be ensonified during the seismic survey would be crab larvae. King and tanner crab eggs are incubated by the females and released as free swimming larvae. It is possible that zooplankters that are very close to the source may react to the shock wave caused by airgun operations. Little or no mortality is expected.

The proposed Aleutian seismic program for 2005 is predicted to have negligible to low physical effects on the various life stages of fish and invertebrates for its one month duration and 4146-km extent. Therefore, physical effects of the proposed program on the fish and invertebrates would be not significant.

Fish and Invertebrate Acoustic Detection and Production.—Hearing in fishes was first demonstrated in the early 1900s through studies involving cyprinids (Parker 1903 and Bigelow 1904 *in* Kenyon et al. 1998). Since that time, numerous methods have been used to test auditory sensitivity in fishes, resulting in audiograms of over 50 species. These data reveal great diversity in fish hearing ability, mostly attributable to various peripheral modes of coupling the ear to internal structures, including the swim bladder. However, the general auditory capabilities of less than 0.2% of fish species are known so far.

For many years, studies of fish hearing have reported that the hearing bandwidth typically extends from below 100 Hz to approximately 1 kHz in fishes without specializations for sound detection, and up to ~7 kHz in fish with specializations that enhance bandwidth and sensitivity. Recently there have been suggestions that certain fishes, including many clupeiforms (herring, shads, anchovies, etc.) may be capable of detecting ultrasonic signals with frequencies as high as 126 kHz (Dunning et al. 1992; Nestler et al. 1992). Studies on Atlantic cod, a non-clupeiform fish, suggested that this species could detect ultrasound at almost 40 kHz (Astrup and Møhl 1993).

Mann et al. (2001) showed that the American shad is capable of detecting sounds up to 180 kHz. They also demonstrated that the gulf menhaden is also able to detect ultrasound, whereas other species

such as the bay anchovy, scaled sardine, and Spanish sardine only detect sounds with frequencies up to ~4 kHz.

Among fishes, at least two major pathways for sound transmission to the ear have been identified. The first and most primitive is the conduction of sound directly from the water to tissue and bone. The fish's body takes up the sound's acoustic particle motion and subsequent hair cell stimulation occurs because of the difference in inertia between the hair cells and their overlying otoliths. These species are known as 'hearing generalists' (Fay and Popper 1999). The second sound pathway to the ears is indirect. The swim bladder or other gas bubble near the ears expands and contracts in volume in response to sound pressure fluctuations, and the motion is then transmitted to the otoliths. While present in most bony fishes, the swim bladder is absent or reduced in many other fish species. Only some species of fish with a swim bladder appear to be sound-pressure sensitive *via* this indirect pathway to the ears; they are called 'hearing specialists'. Hearing specialists have some sort of connection with the inner ear, either *via* bony structures known as Weberian ossicles, extensions of the swim bladder, or a swim bladder more proximate to the inner ear. Hearing specialists' sound-pressure sensitivity is high and their upper frequency range of detection is extended above those species that hear only by the direct pathway. Typically, most fish detect sounds of frequencies up to 2,000-Hz but, as indicated, others have detection ranges that extend to much higher frequencies.

Fish also possess lateral lines that detect water movements. The essential stimulus for the lateral line consists of differential water movement between the body surface and the surrounding water. The lateral line is typically used in concert with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999).

Elasmobranchs (sharks and skates) lack any known pressure-to-displacement transducers such as swim bladders. Therefore, they presumably must rely on the displacement sensitivity of their mechanoreceptive cells. Unlike acoustic pressure, the kinetic stimulus is inherently directional but its magnitude rapidly decreases relative to the pressure component as it propagates outward from the sound source in the near field. It is believed that elasmobranches are most sensitive to low frequencies, those <1 kHz (Corwin 1981).

Because they lack air-filled cavities and are often the same density as water, invertebrates detect underwater acoustics differently than fish. Rather than being pressure sensitive, invertebrates appear to be most sensitive to particle displacement. However, their sensitivity to particle displacement and hydrodynamic stimulation seem poor compared to fish. Decapods, for example, have an extensive array of hair-like receptors both within and upon the body surface that could potentially respond to water- or substrate-borne displacements. They are also equipped with an abundance of proprioceptive organs that could serve secondarily to perceive vibrations. Crustaceans appear to be most sensitive to sounds of low frequencies, those <1,000-Hz (Budelmann 1992; Popper et al. 2001).

Many fish and invertebrates are also capable of sound production. It is believed that these sounds are used for communication in a wide range of behavioral and environmental contexts. The behaviors most often associated with acoustic communication include territorial behavior, mate finding, courtship, and aggression. Sound production provides a means of long-distance communication and communication when underwater visibility is poor (Zelick et al. 1999).

Behavioral Effects.—Because of the apparent lack of serious pathological and physiological effects of seismic energy on marine fish and invertebrates, most concern now centers on the possible effects of exposure to seismic surveys on the distribution, migration patterns, and catchability of fish.

There is a need for more information on exactly what effects such sound sources might have on the detailed behavior patterns of fish and invertebrates at different ranges.

Studies investigating the possible effects of seismic energy on fish and invertebrate behavior have been conducted on both uncaged and caged animals. Studies of change in catch rate regard potential effects of seismic energy on larger spatial and temporal scales than are typical for close-range studies that often involve caged animals (Hirst and Rodhouse 2000). Hassel et al. (2003) investigated the behavioral effects of seismic pulses on caged sand lance in Norwegian waters. The sand lance did exhibit responses to the seismic, including an increase in swimming rate, an upwards vertical shift in distribution, and startle responses. Normal behaviors were resumed shortly after cessation of the seismic source. None of the observed sand lance reacted by burying into the sand.

Engås et al. (1996) assessed the effects of seismic surveying on Atlantic cod and haddock behavior using acoustic mapping and commercial fishing techniques. Results indicated that fish abundance decreased at the seismic survey area, and that the decline in abundance and catch rate lessened with distance from the survey area. Fish abundance and catch rates had not returned to pre-shooting levels five days after cessation of shooting. In other airgun experiments, catch per unit effort (CPUE) of demersal fish declined when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkkeborg 1991; Skalski et al. 1992). Reductions in the catch may have resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish may have changed their swimming and schooling behavior. Fish behavior returned to normal minutes after the sounds ceased.

Marine fish inhabiting an inshore reef off the coast of Scotland were monitored by telemetry and remote camera before, during, and after airgun firing (Wardle et al. 2001). Although some startle responses were observed, the seismic gun firing had little overall effect on the day-to-day behavior of the resident fish.

Other species involved in studies that have indicated fish behavioral responses to underwater sound include rockfish (Pearson et al. 1992), Pacific herring (Schwarz and Greer 1984), and Atlantic herring (Blaxter et al. 1981). The responses observed in these studies were relatively temporary. What is not known is the effect of exposure to seismic energy on fish and invertebrate behaviors that are associated with reproduction and migration.

Studies on the effects of sound on fish behavior have also been conducted using caged or confined fish. Such experiments were conducted in Australia using fish, squid, and cuttlefish as subjects (McCauley et al. (2000a,b). Common observations of fish behavior included startle response, faster swimming, movement to the part of the cage furthest from the seismic source (i.e., avoidance), and eventual habituation. Fish behavior appeared to return pre-seismic state 15–30 min after cessation of seismic shooting. Squid exhibited strong startle responses to the onset of proximate airgun firing by releasing ink and/or jetting away from the source. The squid consistently made use of the 'sound shadow' at the surface, where the sound intensity was less than at 3-m depth. These Australian experiments provided more evidence that fish and invertebrate behavior will be modified at some received sound level. Again, the behavioral changes seem to be temporary.

Christian et al. (2003) conducted an experimental commercial fishery for snow crab before and after the area was exposed to seismic shooting. Although the resulting data were not conclusive, no drastic decrease in catch rate was observed after seismic shooting commenced. Another behavioral investigation by Christian et al. (2003) involved caging snow crabs, positioning the cage 50 m below a seven-gun array, and observing the immediate responses of the crabs to the onset of seismic shooting by

remote underwater camera. No obvious startle behaviors were observed. Anecdotal information from Newfoundland, Canada, indicated that snow crab catch rates showed a significant reduction immediately following a pass by a seismic survey vessel. Other anecdotal information from Newfoundland indicated that a school of shrimp showing on a fishing vessel sounder shifted downwards and away from a nearby seismic source. Effects were temporary in both the snow crab and shrimp anecdotes (Buchanan et al. 2004).

Summary of Behavioral Effects.—As is the case with pathological and physiological effects of seismic on fish and invertebrates, available information is relatively scant and often contradictory. There have been well-documented observations of fish and invertebrates exhibiting behaviors that appeared to be responses to exposure to seismic energy (i.e., startle response, change in swimming direction and speed, and change in vertical distribution), but the ultimate importance of those behaviors is unclear. Some studies indicate that such behavioral changes are very temporary, whereas others imply that fish might not resume pre-seismic behaviors or distributions for a number of days. There appears to be a great deal of inter- and intra-specific variability. In the case of finfish, three general types of behavioral responses have been identified: startle, alarm, and avoidance. The type of behavioral reaction appears to depend on many factors, including the type of behavior being exhibited before exposure, and proximity and energy level of sound source.

During the proposed study, only a small fraction of the available habitat would be ensonified at any given time, and fish species would return to their pre-disturbance behavior once the seismic activity ceased. The proposed Aleutian seismic program for 2005 is predicted to have negligible to low behavioral effects on the various life stages of the fish and invertebrates during the one month study that will survey 4146 km.

Changes in behavior in fish near the airguns might have short-term impacts on the ability of cetaceans to feed near the survey area. However, only a small fraction of the available habitat would be ensonified at any given time, and fish species would return to their pre-disturbance behavior once the seismic activity ceased. Thus, the proposed survey would have little impact on the abilities of marine mammals to feed in the area where seismic work is planned. Some of the fish that do not avoid the approaching airguns (probably a small number) may be subject to auditory or other injuries.

Zooplankters that are very close to the source may react to the shock wave. These animals have an exoskeleton and no air sacs. Little or no mortality is expected. Many crustaceans can make sounds and some crustaceans and other invertebrates have some type of sound receptor. However, the reactions of zooplankters to sound are not known. Some mysticetes feed on concentrations of zooplankton. A reaction by zooplankton to a seismic impulse would only be relevant to whales if it caused a concentration of zooplankton to scatter. Pressure changes of sufficient magnitude to cause this type of reaction would probably occur only very close to the source. Impacts on zooplankton behavior are predicted to be negligible, and this would translate into negligible impacts on feeding mysticetes.

Because of the reasons noted above, the operations are not expected to cause significant impacts on habitats used by marine mammals, or on the food sources that marine mammals use.

X. ANTICIPATED IMPACT OF LOSS OR MODIFICATION OF HABITAT ON MARINE MAMMALS

> The anticipated impact of the loss or modification of the habitat on the marine mammal populations involved.

The effects of the planned activity on marine mammal habitats and food resources are expected to be negligible, as described above. A small minority of the marine mammals that are present near the proposed activity may be temporarily displaced as much as a few kilometers by the planned activity.

During the proposed survey, most marine mammals will be dispersed throughout the study area. Several cetacean species may be feeding in the area at the time of the survey, including the baleen whales that occur there. There are no known feeding aggregations in the study area, and very little of the seismic survey will be in water depths as shallow as those used by gray whales. Steller sea lion rookeries will be avoided by at least 3 n.mi.

The proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, since operations at the various sites will be limited in duration.

XI. MITIGATION MEASURES

> The availability and feasibility (economic and technological) of equipment, methods, and manner of conducting such activity or other means of effecting the least practicable adverse impact upon the affected species or stocks, their habitat, and on their availability for subsistence uses, paying particular attention to rookeries, mating grounds, and areas of similar significance.

For the proposed seismic survey in the Aleutian Islands during June–July 2005, L-DEO will deploy a single GI gun as an energy source, with a discharge volume of up to 105 in^3. The energy from the GI gun will be directed mostly downward. The small size of the GI gun to be used during the proposed study is an inherent and important mitigation measure that will reduce the potential for effects relative to those that might occur with large airgun arrays.

Received sound levels have been estimated by L-DEO in relation to distance from the single GI gun. The radii around the GI gun where received levels would be 180 and 190 dB re 1 µPa (rms) depend on water depth, and are shown in Table 1 (in § I). The 180 and 190 dB levels are shut-down criteria applicable to cetaceans and pinnipeds, respectively, as specified by NMFS (2000).

Vessel-based observers will watch for marine mammals near the GI gun when it is in use. Mitigation and monitoring measures proposed to be implemented for the proposed seismic survey have been developed and refined in cooperation with NMFS during previous L-DEO seismic studies and associated EAs, IHA applications, and IHAs. The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for other L-DEO projects. The measures are described in detail below.

Several cetacean species are known to feed in the area at the time of the proposed survey. However, the number of individual animals expected to be closely approached during the proposed activity will be small in relation to regional population sizes. With the proposed monitoring and shut-

down provisions (see below), any effects on individuals are expected to be limited to behavioral disturbance. That is expected to have negligible impacts on the species and stocks.

The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activity.

Marine Mammal Monitoring

Vessel-based observers will monitor marine mammals near the seismic source vessel during all daytime GI gun operations and during any nighttime start ups of the GI gun. These observations will provide the real-time data needed to implement some of the key mitigation measures. When marine mammals are observed within, or about to enter, designated safety zones (see below) where there is a possibility of significant effects on hearing or other physical effects, GI gun operations will be shut down immediately.

- During daylight, vessel-based observers will watch for marine mammals near the seismic vessel during all periods with shooting and for a minimum of 30 min prior to the planned start of airgun operations after an extended shut down.

- L-DEO proposes to conduct nighttime as well as daytime operations. Observers dedicated to marine mammal observations will not be on duty during ongoing seismic operations at night. At night, bridge personnel will watch for marine mammals (insofar as practical at night) and will call for the GI gun to be shut down if marine mammals are observed in or about to enter the safety radii. If the entire safety radius is visible using vessel lights and NVDs[2] (as may be the case in deep and intermediate waters), then start up of the GI gun from a shut down may occur. Two marine mammal observers will monitor marine mammals near the source vessel for 30 min prior to start up of the GI gun.

Proposed Safety Radii

Received sound levels have been modeled by L-DEO for a single GI gun, in relation to distance and direction from the GI gun (Fig. 2). The model does not allow for bottom interactions, and is most directly applicable to deep water. Based on the model, the distances from the GI gun where sound levels of 190, 180, 170, and 160 dB re 1 µPa (rms) are predicted to be received are shown in the >1000 m line of Table 1 (§ I).

Empirical data concerning the 180, 170 and 160 dB distances have been acquired based on measurements during the acoustic verification study conducted by L-DEO in the northern Gulf of Mexico from 27 May to 3 June 2003 (Tolstoy et al. 2004). Although the results are limited, the data for various airgun configurations showed that water depth affected the radii around the airguns where received level would be 180 dB re 1 µPa (rms), the safety criterion applicable to cetaceans (NMFS 2000). Similar depth-related variation is likely in the 190 dB distances applicable to pinnipeds.

The proposed study area will occur in water ~30–3000 m, although <1% of the survey lines are expected to occur in shallow (<100 m) water. In ***deep*** (>1000 m) water, the safety radii during airgun operations will be the values predicted by L-DEO's model (Table 1). Therefore, the assumed 180- and 190-dB radii are 27 m and 10 m, respectively. For operations in ***shallow*** (<100 m) water, conservative

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[2] See Smultea and Holst (2003), Holst (2004), and Stoltz and MacLean (in prep.) for an evaluation of the effectiveness of night vision equipment for nighttime marine mammal observations.

correction factors were applied to the predicted radii for the GI gun. The 180- and 190-dB radii in shallow water are assumed to be 200 m and 125 m, respectively. In *intermediate* depths (100–1000 m), a 1.5x correction factor was applied to the estimates provided by the model for deep water situations. The assumed 180- and 190-dB radii in intermediate-depth water are 41 m and 15 m, respectively. For more a more detailed explanation on how these safety radii were derived, please refer to the section on "Airgun Description" in § I.

The GI gun will be shut down immediately when marine mammals are detected within or about to enter the appropriate radius: 180 dB (rms) for cetaceans, and 190 dB (rms) for pinnipeds. The 180 and 190 dB shutdown criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS. L-DEO and NSF are aware that NMFS may release new noise-exposure guidelines soon. L-DEO and NSF will be prepared to revise their procedures for estimating numbers of mammals "taken", safety radii, etc., as may be required at some future date by the new guidelines.

Mitigation during Operations

The mitigation and marine mammal monitoring measures listed and described below will be adopted during the proposed seismic program, provided that doing so will not compromise operational safety requirements:

1. speed or course alteration;

2. shut-down procedures;

3. special mitigation measures (shut downs) for the North Pacific right whale;

4. avoidance of encroachment upon critical habitat around Steller sea lion rookeries and haulouts;

5. no start up of GI gun operations at night unless the full 180 dB safety zone is visible; and

6. special mitigation measures for sea otters.

Although a "power-down" procedure is often applied by L-DEO during seismic surveys with larger arrays, powering down will not be possible during the proposed project, as only a single GI gun will be used. Likewise, although "ramp-up" procedures are usually followed by L-DEO prior to airgun operations, ramp ups are impractical for a single GI gun.

Speed or Course Alteration

If a marine mammal is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radius, the vessel's speed and/or direct course may, when practical and safe, be changed in a manner that also minimizes the effect to the planned science objectives. The marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the marine mammal does not approach within the safety radius. If the mammal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or power down or shut down of the GI gun.

Shut-down Procedures

If a marine mammal is detected outside the safety radius but is likely to enter the safety radius, and if the vessel's course and/or speed cannot be changed to avoid having the mammal enter the safety radius,

the GI gun will be shut down before the mammal is within the safety radius. Likewise, if a mammal is already within the safety radius when first detected, the GI gun will be shut down immediately.

GI gun activity will not resume until the marine mammal has cleared the safety radius. The animal will be considered to have cleared the safety radius if it is visually observed to have left the safety radius, or if it has not been seen within the radius for 15 min (small odontocetes and pinnipeds) or 30 min (mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales).

North Pacific Right Whale

Special mitigation measures will be implemented for the North Pacific right whale (*Eubalaena japonica*). The GI gun will be shut down if a North Pacific right whale is sighted from the vessel, even if it is located outside the safety radius, because of the rarity and sensitive status of this species.

Steller Sea Lion Critical Habitat

To the extent practicable, the vessel will avoid entering the critical habitat around Steller sea lion haul outs by planning operations to remain in water depths >30 m. In addition, no-approach zones of Steller sea lion rookeries will be observed, and the vessel will not approach within 3 n.mi. (5.6 km) of the rookeries.

Start up of GI-gun Operations

In order for start up to occur during day or night, the full safety radius must be visible for at least 30 min. During nighttime operations, if the entire safety radius is visible using vessel lights and NVDs (as may be the case in deep and intermediate waters), then start up of the airguns from a shut down may occur. However, lights and NVDs may not be very effective as a basis for monitoring the larger safety radii around the GI gun operating in shallow water. In shallow water, nighttime start ups of the GI gun from a shut-down condition may not to be possible. If the GI gun has been operational before nightfall, it can remain operational throughout the night, even though the entire safety radius may not be visible.

Sea Otters

Sea otters likely will not be encountered during the survey because the seismic track does not come near potential sea otter habitat. In order to assure that any sea otter approached by the operating GI gun is not significantly disturbed, special mitigation measures described in the Environmental Assessment that accompanies this IHA Application will be used.

XII. PLAN OF COOPERATION

Where the proposed activity would take place in or near a traditional Arctic subsistence hunting area and/or may affect the availability of a species or stock of marine mammal for Arctic subsistence uses, the applicant must submit either a plan of cooperation or information that identifies what measures have been taken and/or will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses. A plan must include the following:

(i) A statement that the applicant has notified and provided the affected subsistence community with a draft plan of cooperation;

(ii) A schedule for meeting with the affected subsistence communities to discuss proposed activities and to resolve potential conflicts regarding any aspects of either the operation or the plan of cooperation;

(iii) A description of what measures the applicant has taken and/or will take to ensure that proposed activities will not interfere with subsistence whaling or sealing; and

(iv) What plans the applicant has to continue to meet with the affected communities, both prior to and while conducting activity, to resolve conflicts and to notify the communities of any changes in the operation.

Not applicable. The proposed activity will take place in the Aleutian Islands, and no activities will take place in or near a traditional Arctic subsistence hunting area.

XIII. MONITORING AND REPORTING PLAN

The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding...

L-DEO proposes to sponsor marine mammal monitoring during the present project, in order to implement the proposed mitigation measures that require real-time monitoring, and to satisfy the anticipated monitoring requirements of the Incidental Harassment Authorization.

L-DEO's proposed Monitoring Plan is described below. L-DEO understands that this Monitoring Plan will be subject to review by NMFS, and that refinements may be required.

The monitoring work described here has been planned as a self-contained project independent of any other related monitoring projects that may be occurring simultaneously in the same region. L-DEO is prepared to discuss coordination of its monitoring program with any related work that might be done by other groups insofar as this is practical and desirable.

Vessel-based Visual Monitoring

Vessel-based observers will watch for marine mammals near the seismic source vessel during all daytime GI gun operations and during any nighttime start ups of the airguns. GI gun operations will be suspended when marine mammals are observed within, or about to enter, designated safety radii (see below) where there is a possibility of significant effects on hearing or other physical effects. The marine mammal observers (MMOs) will watch for marine mammals near the seismic vessel during daylight periods with shooting, and for at least 30 min prior to the planned start of airgun operations after an extended shut down of the airguns. If feasible, observations will also be made during daytime periods without airgun operations (e.g., during transits). Observers will not be on duty during ongoing seismic operations at night. At night, bridge personnel will watch for marine mammals (insofar as practical) and will call for the GI gun to be shut down if marine mammals are observed in or about to enter the safety radii. If the airguns are started up at night, two MMOs will monitor marine mammals near the source vessel for 30 min prior to (and during) ramp up using night vision devices (NVDs). Start up will not occur unless the entire safety radius is visible.

During seismic operations, three MMOs will be based aboard the vessel. Observers will be appointed by L-DEO with NMFS concurrence. At least one observer, and when practical, two observers, will monitor marine mammals near the seismic vessel during ongoing daytime seismic operations. Two MMOs will be on watch at least during the 30-min periods preceding start up of the airguns. Use of two simultaneous observers will increase the proportion of the marine mammals present near the source vessel that are detected. MMOs will be on duty in shifts of duration no longer than 4 hours. Bridge personnel additional to the dedicated marine mammal observers will also assist in detecting marine mammals, and implementing mitigation requirements. Before the start of the seismic survey, bridge personnel will be given additional instruction in how to assist with the observations.

The *Kilo Moana* is a suitable platform for marine mammal and turtle observations. When stationed on the flying bridge, the eye level will be ~17.2 m above sea level, and the observer will have a good view around the entire vessel (with small obstructions to the stern of the vessel). If surveying from the bridge, the observer's eye level will be 14.4 m above sea level. During daytime, the MMO(s) will scan the area around the vessel systematically with reticle binoculars (e.g., 7 × 50 Fujinon) and with the naked eye. At night, NVDs will be available (ITT F500 Series Generation 3 binocular-image intensifier or equivalent), when required. Laser rangefinding binoculars (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist with distance estimation. Those are useful in training observers to estimate distances visually, but are generally not useful in measuring distances to animals directly.

The vessel-based monitoring will provide data required to estimate the numbers of marine mammals exposed to various received sound levels, to document any apparent disturbance reactions, and thus to estimate the numbers of mammals potentially "taken" by harassment. It will also provide the information needed in order to shut down the GI gun at times when marine mammals or turtles are present in or near the safety zone. When a mammal or turtle sighting is made, the following information about the sighting will be recorded:

1. Species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, apparent reaction to seismic vessel (e.g., none, avoidance, approach, paralleling, etc.), and behavioral pace.

2. Time, location, heading, speed, activity of the vessel (e.g., operating airguns), sea state, visibility, and sun glare.

The data listed under (2) will also be recorded at the start and end of each observation watch and during a watch, whenever there is a change in one or more of the variables.

All mammal and turtle observations and GI gun shut downs will be recorded in a standardized format. Data will be entered into a custom database using a notebook computer. The accuracy of the data entry will be verified by computerized validity data checks as the data are entered and by subsequent manual checking of the database. Those procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical, or other programs for further processing and archiving.

Results from the vessel-based observations will provide

1. The basis for real-time mitigation (GI gun shut down).

2. Information needed to estimate the number of marine mammals potentially taken by harassment, which must be reported to NMFS.

3. Data on the occurrence, distribution, and activities of marine mammals in the area where the seismic study is conducted.

4. Information to compare the distance and distribution of marine mammals relative to the source vessel at times with and without seismic activity.

5. Data on the behavior and movement patterns of marine mammals seen at times with and without seismic activity.

Reporting

A report will be submitted to NMFS within 90 days after the end of the cruise. The report will describe the operations that were conducted and the marine mammals that were detected near the operations. The report will be submitted to NMFS, providing full documentation of methods, results, and interpretation pertaining to all monitoring. The 90-day report will summarize the dates and locations of seismic operations, and all marine mammal sightings (dates, times, locations, activities, associated seismic survey activities). The report will also include estimates of the amount and nature of potential "take" of marine mammals by harassment or in other ways.

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE

Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects.

L-DEO will coordinate the planned project with other parties that may or are planning to sponsor, conduct or participate in marine mammal, acoustical, and oceanographic studies in the same region during the corresponding part of 2004.

This EA has been adopted by the NSF primarily to address issues relating to the request that an IHA be issued by NMFS to authorize "taking by harassment" (disturbance) of small numbers of cetaceans and pinnipeds during L-DEO's planned project activities. In addition, L-DEO and NSF will coordinate with other applicable Federal and State agencies, and will comply with their requirements. Actions of this

type that are underway in parallel with the request for issuance of an IHA, or will follow the submission of the IHA Application and associated EA, include the following:

- Submission in late December 2004 or early January 2005 of a determination to the State of Alaska confirming that the project is in compliance with state and local Coastal Management Programs.

- Coordination on 29 November 2004 with the NMFS Alaska Region, Anchorage, AK, concerning compliance with requirements within areas designated as Critical Habitat for Steller sea lions.

- Following the submission of the IHA Application and associated EA, a formal Section 7 consultation will be conducted with NMFS regarding Steller sea lions and operations in the project area.

- Coordination with the Army Corps of Engineers regarding a Nationwide Permit #5 (permission for bottom contact), application submission, and authorization on 16 December to proceed with the survey.

- Coordination with the Alaska Department of Fish and Game's regional supervisors for the Commercial Fisheries Division (Forrest Bowers and Karla Bush for Western Region), concerning fisheries issues in state waters.

- Coordination with the Alaska Native Harbor Seal Commission, the Alaska Sea Otter and Steller Sea Lion Commission, and local communities within the project area with regard to potential concerns about interactions with subsistence hunting and fisheries.

- Coordination beginning on 1 November 2004 with the USFWS, Marine Mammals Management, Anchorage, AK, regarding concerns about possible impacts on sea otters.

- Following the submission of the IHA Application and associated EA, a conference will also be conducted with the USFWS regarding project operations and sea otters.

- Coordination with the Alaska Maritime National Wildlife Refuge regarding potential disturbance to seabirds.

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APPENDIX A:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [3]

The following subsections review relevant information concerning the potential effects of airgun sounds on marine mammals. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA Applications and EAs submitted to NMFS during 2003 for other L-DEO projects. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep in the eastern tropical Pacific, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, southern Gulf of Mexico (Yucatan Peninsula), Oregon, southeast Alaska, and off the west coast of Central America. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

(a) Categories of Noise Effects

The effects of noise on marine mammals are highly variable, and can be categorized as follows (based on Richardson et al. 1995):

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;

2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it;

3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;

4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;

5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or sonar pulses could cause masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;

6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical effects. Received sound levels must far exceed the animal's hearing

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[3] By **W. John Richardson** and **Valerie D. Moulton**, LGL Ltd., environmental research associates. Revised December 2004.

threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

(b) Hearing Abilities of Marine Mammals

The hearing abilities of marine mammals are functions of the following (Richardson et al. 1995; Au et al. 2000):

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise).

2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).

3. The ability to localize sound direction at the frequencies under consideration.

4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments also show that they hear and may react to many man-made sounds including sounds made during seismic exploration.

Toothed Whales

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are at present no specific data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales.

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, the sounds are sufficiently strong that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). However, there is no evidence that small odontocetes react to airgun pulses at such long distances, or even at intermediate distances where sound levels are well above the ambient noise level (see below).

The multi-beam sonar operated from the Kilo Moana emits pulsed sounds at 12 kHz. That frequency is within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the multi-beam sonar will be readily audible to these animals when they are within the narrow angular extent of the transmitted sound beam.

Baleen Whales

The hearing abilities of baleen whales have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Baleen whales also reacted to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see Richardson et al. 1995 for a review). Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpbacks, to >15 kHz (Au et al. 2001). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991,

1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly. Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where seismic (or sonar) sounds would be detectable and yet often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum detectable levels (Malme et al. 1984, 1988; Richardson et al. 1986, 1995; McCauley et al. 2000a; Johnson 2002).

Pinnipeds

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211*ff*; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid (hair) seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to about 1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 µPa at 100 Hz (Kastak and Schusterman 1998). The northern elephant seal (not an Atlantic/Gulf of Mexico species) appears to have better under-water sensitivity than the harbor seal, at least at low frequencies (Kastak and Schusterman 1998, 1999).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for hair seals (harbor or elephant seal).

The underwater hearing of a walrus has recently been measured at frequencies from 125 Hz to 15 kHz (Kastelein et al. 2002). The range of best hearing was from 1–12 kHz, with maximum sensitivity (67 dB re 1 µPa) occurring at 12 kHz (Kastelein et al. 2002).

Sirenians

The hearing of manatees is sensitive at frequencies below 3 kHz. A West Indian manatee that was tested using behavioral methods could apparently detect sounds from 15 Hz to 46 kHz (Gerstein et al. 1999). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral testing suggests their best sensitivity is at 6 to 20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

(c) Characteristics of Airgun Pulses

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10 to 20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain some energy up to 500–1000 Hz and above (Goold and Fish 1998). The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds to which whales and other marine mammals are routinely exposed. The only sources with higher or comparable effective source levels are explosions.

The peak-to-peak source levels of the 2- to 20-airgun arrays used by L-DEO during various projects range from 236 to 263 dB re 1 µPa at 1 m, considering the frequency band up to about 250 Hz. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

Several important mitigating factors need to be kept in mind. *(1)* Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for much longer durations than seismic pulses. *(2)* Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-target areas. *(3)* An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote peak-to-peak levels, in bar-meters or (less often) dB re 1 µPa · m. The peak (= zero-to-peak) level for the same pulse is typically about 6 dB less. In the biological literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically about 10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy level, in dB re 1 µPa2 · s. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse. Near the source, the predominant part of a seismic pulse is about 10 to 20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was about 300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995). Paired measurements of received airgun sounds at depths of 3 m *vs.* 9 m or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (Tolstoy et al. 2004a,b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are low—below 120 dB re 1 µPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). Considerably higher levels can occur at distances out to several kilometers from an operating airgun array.

(d) Masking Effects of Seismic Surveys

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds.

Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz and considerably lower spectrum levels above 1000 Hz. These low frequencies are mainly used by mysticetes, but generally not by odontocetes, pinnipeds, or sirenians. An industrial sound source will reduce the effective communication or echolocation distance only if its frequency is close to that of the marine mammal signal. If little or no overlap occurs between the industrial noise and the frequencies used, as in the case of many marine mammals vs. airgun sounds,

communication and echolocation are not expected to be disrupted. Furthermore, the discontinuous nature of seismic pulses makes significant masking effects unlikely even for mysticetes.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or possibly to shift their peak frequencies in response to strong sound signals (Dahlheim 1987; Au 1993; Lesage et al. 1999; Terhune 1999; reviewed in Richardson et al. 1995:233*ff, 364ff*). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses, and it is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking.

(e) Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. In the terminology of the 1994 amendments to the MMPA, seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

There has been debate regarding how substantial a change in behavior or mammal activity is required before the animal should be deemed to be "taken by Level B harassment". NMFS has recently stated that

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do no disrupt the animal's overall behavioral pattern of breathing under the circumstances), do not rise to a level requiring a small take author-ization." (NMFS 2001, p. 9293).

Based on this guidance from NMFS, we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Behavioral reactions of marine mammals to sound are difficult to predict. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed

to a particular level of industrial sound. This likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The definitions of "taking" in the U.S. Marine Mammal Protection Act, and its applicability to various activities, are presently (autumn 2003) under active consideration by the U.S. Congress. Some changes are likely. Also, the U.S. National Marine Fisheries Service is considering the adoption of new criteria concerning the noise exposures that are (and are not) expected to cause "takes" of various types. Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, and small toothed whales.

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the main studies on this topic are the following: Malme et al. 1984, 1985, 1988; Richardson et al. 1986, 1995, 1999; Ljungblad et al. 1988; Richardson and Malme 1993; McCauley et al. 1998, 2000a; Miller et al. 1999.

Prior to the late 1990s, it was thought that bowhead whales, gray whales, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of about 160 to 170 dB re 1 μPa rms, but that subtle behavioral changes sometimes become evident at somewhat lower received levels. Recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) may show strong avoidance at received levels somewhat lower than 160–170 dB re 1 μPa rms. The observed avoidance reactions involved movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources. In the case of the migrating whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Humpback Whales.—McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with source level 227 dB re 1 μPa·m (p-p). They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single gun. Avoidance reactions began at 5–8 km from the array and those reactions kept most pods about 3–4 km from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 μPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e.,

the closest point of approach of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single gun. However, some individual humpback whales, especially males, approached within distances 100–400 m, where the maximum received level was 179 dB re 1 µPa rms.

Humpback whales summering in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 µPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa on an approximate rms basis.

Bowhead Whales.—Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6 to 99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 µPa·m at a distance of 7.5 km, and swam away when it came within about 2 km. Some whales continued feeding until the vessel was 3 km away. Feeding bowhead whales tend to tolerate higher sound levels than migrating whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. In 1996–98, a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea (Miller et al. 1999; Richardson et al. 1999). Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20–30 km, and that few bowheads approached within 20 km. Received sound levels at those distances were only 116–135 dB re 1 µPa (rms). Some whales apparently began to deflect their migration path when still as much as 35 km away from the airguns. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped. These and other data suggest that migrating bowhead whales are more responsive to seismic pulses than were summering bowheads.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1µPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6 to 2.8 km from an airgun array with a source level of 250 dB (0-pk) in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 160 dB re 1 µPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in³ array operating off

central California (CPA = closest point of approach). This would occur at an average received sound level of about 170 dB (rms). Some slight behavioral changes were noted at received sound levels of 140 to 160 dB (rms).

There was no indication that western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001. However, there were indications of subtle behavioral effects and (in 2001) localized avoid-ance by some individuals (Johnson 2002; Weller et al. 2002).

Rorquals.—Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003). Baleen whale pods sighted from the ship were found to be at a median distance of about 1.6 km from the array during shooting and 1.0 km during periods without shooting (Stone 2003). Baleen whales, as a group, made more frequent alterations of course (usually away from the vessel) during shooting compared with periods of no shooting (Stone 2003). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, recent studies of humpback and especially migrating bowhead whales show that reactions, including avoidance, sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel are biased.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the seismic array.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. Gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A in Malme et al. 1984). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years. Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were

involved in these repeated observations (within and between years) in strongly ensonified areas. It is also not known whether whales that tolerate exposure to seismic pulses are stressed.

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales, and none similar in size and scope to the studies of humpback, bowhead, and gray whales mentioned above. However, systematic work on sperm whales is underway.

Delphinids and Similar Species.—Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of operating seismic vessels. Authors reporting cases of small toothed whales close to the operating airguns have included Duncan (1985), Arnold (1996), and Stone (2003). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the guns were firing. However, in Puget Sound, Dall's porpoises observed when a 6000 in^3, 12–16-airgun array was firing tended to be heading away from the boat (Calambokidis and Osmek 1998).

Goold (1996a,b,c) studied the effects on common dolphins, *Delphinus delphis*, of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone 180-m aft. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km radius from the guns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

Observers stationed on seismic vessels operating off the United Kingdom from 1997–2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods of shooting. Except for pilot whales, all of the small odontocete species tested, including killer whales, were found to be significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales showed few reactions to seismic activity. The displacement of the median distance from the array was ~0.5 km or more for most species groups. Killer whales also appear to be more tolerant of seismic shooting in deeper waters.

For all small odontocete species, except pilot whales, that were sighted during seismic surveys off the United Kingdom in 1997–2000, the numbers of positive interactions with the survey vessel (e.g., bow-riding, approaching the vessel, etc.) were significantly fewer during periods of shooting. All small odontocetes combined showed more negative interactions (e.g., avoidance) during periods of shooting. Small odontocetes, including white-beaked dolphins, *Lagenorhynchus* spp., and other dolphin spp. showed a tendency to swim faster during periods with seismic shooting; *Lagenorhynchus* spp. were also observed to swim more slowly during periods without shooting. Significantly fewer white-beaked dolphins, *Lagenorhynchus* spp., harbor porpoises, and pilot whales traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting.

Captive bottlenose dolphins and beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). Finneran et al. (2002) exposed a captive bottlenose dolphin and white whale to single impulses from a watergun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a white whale exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound (pk-pk level >200 dB re 1 µPa) before exhibiting the aversive behaviors mentioned above.

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be relevant as an indicator of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 µPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and other odontocetes. Aside from the potential for TTS, the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

Beaked Whales.—There are no specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly. Northern bottle nose whales sometimes are quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001). However, those vessels were not emitting airgun pulses.

There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There has been a recent (Sept. 2002) stranding of Cuvier's beaked whales in the Gulf of California (Mexico) when the L-DEO vessel *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002). Another stranding of Cuvier's beaked whales in the Galapagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002). The evidence with respect to

seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 2002).

Sperm Whales.—All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, sperm whales in the Gulf of Mexico may have moved away from a seismic vessel (Mate et al. 1994).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in U.K. waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 µPa pk-pk (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Jochens and Biggs 2003), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate 2003). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels 143–148 dB re 1 µPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Jochens and Biggs 2003). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm. to LGL Ltd.); the broadband rms value would be somewhat higher. Although the sample size from the initial work was small (four whales during two experiments), the results are consistent with those off northern Norway.

Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are no specific data on responses of beaked whales to seismic surveys, but it is likely that most if not all species show strong avoidance. There is increasing evidence that some beaked whales may strand after exposure to strong noise from sonars. Whether they ever do so in response to seismic survey noise is unknown.

Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies in recent years. Monitoring studies in the Beaufort Sea during

1996–2001 provide a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Pinnipeds exposed to seismic surveys have also been observed during recent seismic surveys along the USWW. Some limited data are available on physiological responses of seals exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, grey seals exposed to noise from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong noise pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the United Kingdom, a radio-telemetry study has demonstrated short-term changes in the behavior of harbor (=common) seals and grey seals exposed to airgun pulses (Thompson et al. 1998). In this study, harbor seals were exposed to seismic pulses from a 90 in^3 array ($3 \times 30\,in^3$ airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after seismic stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m. All grey seals exposed to a single 10 in^3 airgun showed an avoidance reaction. Seals moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as all grey seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions "typically ignored the vessel and array. When [they] displayed behavior modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array (Arnold 1996). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating; both species tended to orient away whether or not the airguns were firing (Calambokidis and Osmek 1998).

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). These seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating then when they were not (Moulton and Lawson 2002). However, these avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the array. The behavioral data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and proportions of seals engaged in other recognizable behaviors, e.g. "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

Fissipeds.—Behavior of sea otters along the California coast was monitored by Riedman (1984, 1984) while they were exposed to a single 100 in^3 airgun and a 4089 in^3 array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Otters also did not respond noticeably to the single airgun. The results suggest that sea otters are less responsive to marine seismic pulses than are baleen whales. Also, sea otters spend a great deal of time at the surface feeding and grooming. While at the surface, the potential noise exposure of sea otters would be much reduced by the pressure release effect at the surface.

(f) Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this in the case of exposure to sounds from seismic surveys. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shutdown) radii planned for numerous seismic surveys. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid Temporary Threshold Shift (TTS) let alone permanent auditory injury, at least for delphinids.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might cause hearing impairment. In addition, many cetaceans are likely to show some avoidance of the area with ongoing seismic operations (see above). In these cases, the avoidance responses of the animals themselves will reduce or avoid the possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds.

Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. However, it is a temporary phenomenon, and is generally not considered to represent physical damage or "injury". Rather, the onset of TTS is an indicator that, if the animals is exposed to higher levels of that sound, physical damage is ultimately a possibility.

The magnitude of TTS depends on the level and duration of noise exposure, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

Toothed Whales.—Ridgway et al. (1997) and Schlundt et al. (2000) exposed bottlenose dolphins and beluga whales to single 1-s pulses of underwater sound. TTS generally became evident at received levels of 192 to 201 dB re 1 µPa rms at 3, 10, 20, and 75 kHz, with no strong relationship between frequency and onset of TTS across this range of frequencies. At 75 kHz, one dolphin exhibited TTS at 182 dB, and at 0.4 kHz, no dolphin or beluga exhibited TTS after exposure to levels up to 193 dB (Schlundt et al. 2000). There was no evidence of permanent hearing loss; all hearing thresholds returned to baseline values at the end of the study.

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were of 5.1–13 ms in duration and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received SPL (sound pressure level) of 221 dB re 1 µPa produced no more than a slight and temporary reduction in hearing.

A similar study was conducted by Finneran et al. (2002) using an 80 in^3 water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study. Water gun impulses were expected to contain proportionally more energy at higher frequencies than airgun pulses (Hutchinson and Detrick 1984). "Masked TTS" (MTTS) was observed in a beluga after exposure to a single impulse with peak-to-peak pressure of 226 dB re 1 µPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 µPa^2 ·s. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with peak-to-peak pressure of 228 dB re 1 µPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 µPa^2 · s (Finneran et al. 2000, 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds; the reference to masking (MTTS) refers to the fact that these measurements were obtained under conditions with substantial (but controlled) background noise. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10–13 ms.

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 s or shorter, generally at frequencies higher than the predominant frequencies in airgun pulses. With single short pulses, the TTS threshold appears to be (to a first approximation) a function of the energy content of the pulse (Finneran et al. 2002). The degree to which this generalization holds for other types of signals is unclear (Nachtigall et al. 2003). In particular, additional data are needed in order to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. Given the results of the afore-mentioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 μPa rms (~221–226 dB pk-pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel.

To better characterize this radius, it would be necessary to determine the total energy that a mammal would receive as an airgun array approached, passed at various CPA distances, and moved away. (CPA = closest point of approach.) At the present state of knowledge, it would also be necessary to assume that the effect is directly related to total energy even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, is a data gap

Baleen Whales.—There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. However, in practice during seismic surveys, no cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS. (See above for evidence concerning avoidance responses by baleen whales.) This assumes that the ramp up (soft start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed above, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Pinnipeds.—TTS thresholds for pinnipeds exposed to brief pulses (either single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels (rms) of ~178 and 183 dB re 1 μPa and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations. For sounds of relatively long duration (20–22 min), Kastak et al. (1999) reported that they could induce mild TTS in California sea lions, harbor seals, and northern elephant seals by exposing them to underwater octave-band noise at frequencies in the 100–2000 Hz range. Mild TTS became evident when the received levels were 60–75 dB above the respective hearing thresholds, i.e., at received levels of about 135–150 dB. Three of the five subjects showed shifts of ~4.6–4.9 dB and all recovered to baseline hearing sensitivity within 24 hours of exposure. Schusterman et al. (2000) showed that TTS thresholds of these seals were somewhat lower when the animals were exposed to the sound for 40 min than for 20–22 min, confirming that there is a duration effect in pinnipeds. There are some indications that, for corresponding durations of sound, some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes (Kastak et al. 1999; Ketten et al. 2001; *cf*. Au

et al. 2000). However, more recent indications are that TTS onset in the most sensitive pinniped species studied (harbor seal) may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2004).

> ***Likelihood of Incurring TTS.***—A marine mammal within a radius of ≤100 m around a typical array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel.

As shown above, most cetaceans show some degree of avoidance of seismic vessels operating an airgun array. It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. However, TTS would be more likely in any odontocetes that bow-ride or otherwise linger near the airguns. While bow-riding, odontocetes would be at or above the surface, and thus not exposed to strong sound pulses given the pressure-release effect at the surface. However, bow-riding animals generally dive below the surface intermittently. If they did so while bow-riding near airguns, they would be exposed to strong sound pulses, possibly repeatedly. If some cetaceans did incur TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are not as strong or consistent as those of cetaceans (see above). Pinnipeds occasionally seem to be attracted to operating seismic vessels. As previously noted, there are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. It is not known whether pinnipeds near operating seismic vessels, and especially those individuals that linger nearby, incur significant TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 μPa (rms). The corresponding limit for pinnipeds has been set at 190 dB, although the HESS Team (1999) recommended 180 dB for pinnipeds in California. The 180 and 190 dB (rms) levels are ***not*** considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before any TTS measurements for marine mammals were available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As discussed above, TTS data that have subsequently become available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 μPa rms. Furthermore, it should be noted that mild TTS is not injury, and in fact is a natural phenomenon experienced by marine and terrestrial mammals (including humans).

It has been shown that most large whales tend to avoid ships and associated seismic operations. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. (Three species of baleen whales that have been exposed to pulses from single airguns showed avoidance (Malme et al. 1984–1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b). This strongly suggests that baleen whales will begin to move away during the initial stages of a ramp-up, when a single airgun is fired.) Thus, whales will likely not be exposed to high levels of airgun sounds. Likewise, any whales close to the trackline could move away before the sounds from the approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for whales to be close enough to an airgun array to

experience TTS. Furthermore, in the event that a few individual cetaceans did incur TTS through exposure to airgun sounds, this is a temporary and reversible phenomenon.

Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the likelihood that some mammals close to an airgun array might incur at least mild TTS (see Finneran et al. 2002), there has been speculation about the possibility that some individuals occurring very close to airguns might incur TTS (Richardson et al. 1995, p. 372*ff*).

Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times can result in PTS even though their levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not nearly as fast as that of explosions, which are the main concern in this regard.

Some factors that contribute to onset of PTS, at least in terrestrial mammals, are as follows:

- exposure to single very intense sound,
- repetitive exposure to intense sounds that individually cause TTS but not PTS, and
- recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) has reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with rather rapid rise time.

Sound impulse duration, peak amplitude, rise time, and number of pulses are the main factors thought to determine the onset and extent of PTS. Based on existing data, Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. If we assume that the TTS threshold for exposure to a series of seismic pulses may be on the order of 220 dB re 1 µPa (pk-pk) in odontocetes, then the PTS threshold might be as high as 240 dB re 1 µPa (pk-pk). In the units used by geophysicists, this is 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson et al. 1995:137; Caldwell and Dragoset 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and pinnipeds may be lower, and thus may extend to a somewhat greater distance. However, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. Pinnipeds, on the other hand, often do not show strong avoidance of operating airguns.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales. Commonly-applied monitoring and mitigation measures, including visual monitoring, course alteration, ramp ups, and power downs or shut downs of the airguns when mammals are seen within the "safety radii", would minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

(g) Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding. However, the association of mass strandings of beaked whales with naval exercises and, in a recent (2002) case, an L-DEO seismic survey, has raised the possibility that beaked whales may be especially susceptible to injury and/or behavioral reactions that can lead to stranding when exposed to strong pulsed sounds.

In March 2000, several beaked whales that had been exposed to repeated pulses from high intensity, mid-frequency military sonars stranded and died in the Providence Channels of the Bahamas Islands, and were subsequently found to have incurred cranial and ear damage (NOAA and USN 2001). Based on post-mortem analyses, it was concluded that an acoustic event caused hemorrhages in and near the auditory region of some beaked whales. These hemorrhages occurred before death. They would not necessarily have caused death or permanent hearing damage, but could have compromised hearing and navigational ability (NOAA and USN 2001). The researchers concluded that acoustic exposure caused this damage and triggered stranding, which resulted in overheating, cardiovascular collapse, and physiological shock that ultimately led to the death of the stranded beaked whales. During the event, five naval vessels used their AN/SQS-53C or -56 hull-mounted active sonars for a period of 16 h. The sonars produced narrow (<100 Hz) bandwidth signals at center frequencies of 2.6 and 3.3 kHz (-53C), and 6.8 to 8.2 kHz (-56). The respective source levels were usually 235 and 223 dB re 1 µPa, but the -53C briefly operated at an unstated but substantially higher source level. The unusual bathymetry and constricted channel where the strandings occurred were conducive to channeling sound. That, and the extended operations by multiple sonars, apparently prevented escape of the animals to the open sea. In addition to the strandings, there are reports that beaked whales were no longer present in the Providence Channel region after the event, suggesting that other beaked whales either abandoned the area or perhaps died at sea (Balcomb and Claridge 2001).

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. Another stranding of beaked whales (15 whales) happened on 24–25 September 2002 in the Canary Islands, where naval maneuvers were taking place. A recent paper concerning the Canary Islands stranding concluded that cetaceans might be subject to decompression injury in some situations (Jepson et al. 2003). If so, this might occur if they ascend unusually quickly when exposed to aversive sounds. Previously it was widely assumed that diving marine mammals are not subject to the bends or air embolism.

It is important to note that seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by the types of airgun arrays used to profile sub-sea geological structures are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2 to 10 kHz, generally with a relatively narrow bandwidth at any one time (though the center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to hearing damage and, indirectly, mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

As discussed earlier, there has been a recent (Sept. 2002) stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the L-DEO/NSF vessel R/V *Maurice Ewing* was underway in the general area (Malakoff 2002). The airgun array in use during that project was the *Ewing*'s 20-airgun 8490-in^3 array. This might be a first indication that seismic surveys can have effects, at least on beaked whales, similar to the suspected effects of naval sonars. However, the evidence linking the Gulf of California strandings to the seismic surveys is inconclusive, and to this date is not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multi-beam bathy-metric sonar at the same time but, as discussed elsewhere, this sonar had much less potential than the aforementioned naval sonars to affect beaked whales. Although the link between the Gulf of California strandings and the seismic (plus multi-beam sonar) survey is inconclusive, this plus the various incidents involving beaked whale strandings "associated with" naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

(h) Non-auditory Physiological Effects

Possible types of non-auditory physiological effects or injuries that might theoretically occur in marine mammals exposed to strong underwater sound might include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of these effects occur in marine mammals exposed to sound from airgun arrays. However, there have been no direct studies of the potential for airgun pulses to elicit any of these effects. If any such effects do occur, they would probably be limited to unusual situations. Those could include cases when animals are exposed at close range for unusually long periods, or when the sound is strongly channeled with less-than-normal propagation loss, or when dispersal of the animals is constrained by shorelines, shallows, etc.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). However, there is essentially no information about the occurrence of noise-induced stress in marine mammals. Also, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that signif-

icant physiological stress would develop. This is particularly so in the case of seismic surveys where the tracklines are long and/or not closely spaced, as is the case for most two-dimensional seismic surveys.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at this frequency, the ensuing resonance could cause damage to the animal. There may also be a possibility that high sound levels could cause bubble formation in the blood of diving mammals that in turn could cause an air embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). A recent workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002).

Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding and participants acknowledged that more research is needed in this area. Jepson et al. (2003) suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles in 14 beaked whales were stranded in the Canary Islands close to the site of an international naval exercise in September 2002. If cetaceans are susceptible to decompression sickness, that might occur if they ascend unusually quickly when exposed to aversive sounds. However, the interpretation that the effect was related to decompression injury is unproven (Piantadosi and Thalmann 2004; Fernández et al. 2004). Even if that effect can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds. The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound.

As noted in the preceding subsection, a recent paper (Jepson et al. 2003) has suggested that cetaceans can at times be subject to decompression sickness. If so, this could be another mechanism by which exposure to strong sounds could, indirectly, result in non-auditory injuries and perhaps death.

In summary, very little is known about the potential for seismic survey sounds to cause either auditory impairment or other non-auditory physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects.

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